How to Build up Furnace Efficiency

By

JOS. W. HAYS
COMBUSTION ENGINEER

How to Build Up Furnace Efficiency

A Hand-book of Fuel Economy

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"The Chemistry of Combustion," "Combustion and Smokeless Furnaces," "How to Get More Power from Coal," "How to Stop the Fuel Wastes," etc.

SEVENTH EDITION

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HOW TO BUILD UP FURNACE EFFICIENCY

(In Five Reels)

PREFACE TO THE SEVENTH EDITION.

In the early part of 1908 the author tendered a manuscript to the editor of an engineering magazine. It was returned with the following comment:

"Your paper is too technical. We get more technical articles than we can use. We want practical articles written in a popular way and we can't get them. Cut out the high-brow stuff and let us have something that the great mass of our readers can peruse with interest and profit."

The result of this advice was the first edition of "How to Build Up Furnace Efficiency", published in 1908. It was brought out with many misgivings. Was it really possible to treat the rather technical subject of combustion in a really popular way,—something that had never been attempted by any one before? Would the public want such a treatment even if the treatment were successful? These questions were not long in being answered. The first edition was exhausted, almost as soon as the announcement of publication was made. Succeeding and larger editions followed the first one. The book has now been out of print for more than a year and a word of apology is due to the many people who have ordered copies without being able to get them.

This edition has been held until the author could find time for the rather laborious work of revision. Many things were omitted in the previous editions that should have been said and some things were said that might have been omitted. There were no illustrations and that was a mistake. In the present edition, sufficient charts, diagrams and illustrations are used to make clear some of the things that it is hard to explain in the printed page. Certain instruments and apparatus designed by the author are illustrated. In showing these it is not intended to disparage other apparatus of like character. The illustrations are given for the sole purpose of showing the "tools" that

the author has used in prosecuting combustion studies and in working out specific furnace efficiency problems in many plants.

It is in no spirit of self-flattery that the author refers to the past success of his book. If credit is due any one it belongs to the editor who offered the advice above quoted. The author feels that a real service is being performed in passing this advice along to other writers. Let us stop writing for technical men who are already well grounded in all the theory of engineering. There are relatively few of such men as compared with the great multitude who want results first and who are content to let theories rest until results have been accomplished. Treat the engineering subject in a really popular way and your book will be read by appreciative thousands. Treat it in a really technical way and it will be read by a few hundreds.

Very little is said in this book relating to the theory of combustion. I have treated of that elsewhere* and with as much lucidity of explanation and illustration as possible, giving to the discussion of theory the same general style of treatment that is here given to the discussion of practice.

In the present edition of "How to Build Up Furnace Efficiency" as in the previous ones, the sole effort has been to show the Manager, Superintendent, Engineers and Firemen of the power plant how they may proceed at once to actually work a real reduction in the coal bills. To this practical end no understanding of theories is necessary. The unlettered fireman may become an expert flue gas analyst and reach the very top notch of efficiency in the combustion of fuel without knowing or caring what the atomic weight of carbon may be or why one atom of carbon unites with two of oxygen to form the gas CO_2. It has been represented and it is generally understood that the contrary is true. No more mischievous representation was ever made with reference to any engineering proposition. It is costing the power plants of the country millions of dollars. The average steam plant wastes a quarter of its fuel. It will go

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*See "The Chemistry of Combustion" 4 Vols.—Published by the Author.

on wasting that quarter until it is recognized that the men to stop the waste are the ones who are doing the wasting.

To burn coal or any other fuel economically is mainly a matter of method and as the method to be used varies with the character of the fuel and the conditions under which it is to be burned, the use of certain apparatus to determine the proper method is necessary in every power plant. It would be, indeed, unfortunate if the apparatus called for special skill or special knowledge on the part of the user. Any man who can read a scale and watch the flickering flame of a tallow candle is qualified to bring any boiler furnace up to the highest state of efficiency consistent with the fuel and the furnace equipment. It will not be disputed that your fireman is able to read a thermometer and tell you how cold or how hot it may be in the boiler room, or that he is competent to use platform scales and weigh your coal. It is not considered that as a preliminary to using the thermometer one must understand the involved mathematics on which the science of thermometry depends or that as a preliminary to weighing a barrow of coal one must be able to explain the laws of the lever discovered by Archimedes. You are familiar with scales and thermometers and you go ahead and use them. You are not familiar with draft gages and gas analyzers,—hence you believe that a diploma from a technical school is necessary before you can use them.

Every statement and recommendation made by the author has been proved by actual experiment and practice to the satisfaction of many people. Try the methods suggested before you pass judgment upon them.

The author feels called upon to apologize for the frequent use of the pronoun "I" in the pages that follow. The reader must understand that every line of the book has been written right out of the writer's personal experiences and in setting these forth the pronoun in the first person has obtruded itself repeatedly.

The author does not claim to be "the law and the prophets" on the subject treated. The reader must take the writer's opinions and experiences for what they are worth upon their face.

Anecdotes have been liberally used throughout the book for purposes of illustration and in deference to these the author has followed a narrative style of writing which it is hoped may assist in sustaining the reader's interest until he has finished the book.

Combustion is a dry subject when considered as an abstract proposition. It is not a dry subject when "human interest" is injected into it. It even has its humorous phases.

The author believes that the methods of "spotting" and stopping fuel wastes described in this book are extremely simple. They may not appear so to the reader. It is difficult to describe a very simple operation to a person who is entirely unacquainted with it and in preparing the book the author has assumed that the reader is not familiar with the subject discussed. It is quite probable that many persons reading the book are better grounded in both the theory and the practice of the matter than the author. To such as these no apology is offered, because the book is not written for them.

The author confesses to the use of rather unvarnished language in some places and he knows that the Manager and Engineer will accept his criticisms with the same good nature in which they are offered.

JOS. W. HAYS,

Rogers Park, Chicago, U. S. A. January 2, 1914.

Never Read a Book
Until You Have Read
the Author's Preface.

How to Build Up Furnace Efficiency

CHAPTER I.

WHY YOUR FUEL IS WASTED

The purpose of this book is to show WHY, HOW and WHERE fuel is wasted in your boiler room. Having shown the causes of loss specific means of stopping the wastes will be suggested. A diagnosis of the sick man's case will not cure him. There must be a prescription following the diagnosis and the actual taking of the medicine must follow the prescription.

The sickest thing about your factory plant is the boiler room. You have been so busy putting the "prod" into production that you have allowed the boiler room to look after itself in its own way. And the result is exactly what might be expected in such circumstances. You are wasting just about a quarter of your fuel. When I say "you", I am referring to the average steam power plant and when I say a "quarter of your fuel" I am referring to the preventable wastes that occur in the actual burning of the coal. I am not including the necessary heat losses which are considerable. I am not including the losses chargeable to the boiler proper as distinct from the furnace, such as the great waste due to scale, improper baffling etc., or the loss due to soot which should be charged jointly to the furnace and boiler. If we add these other wastes to the 25 per cent loss that must be charged against the fireman and the furnace the total will be a staggering figure. I have treated elsewhere* at some length of these "other wastes" and we shall be reasonably occupied in this book if we do justice to the subject of furnace efficiency and allow the boiler for the time being to look after itself. Something will be said about soot and scale but with these exceptions the book will stick to its title, "How to Build Up Furnace Efficiency".

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*See the magazine publications of The System Company, Chicago.

Fuel Wastes Between the Mine and the Machine

	DIRECT FUEL WASTES	Preventable losses B. T. U.	Non-preventable losses B. T. U.
1	Lost—By weather waste between mine and factory	....	290,000
2	Lost—In handling at the plant	290,000	....
3	Lost—In the ash—non-preventable	....	284,200
4	Lost—In the ash—preventable	1,136,800	....
5	Lost—By radition—non-preventable	....	284,200
6	Lost—By radition—preventable	852,600	....
7	Lost—By incomplete combustion	204,908	....
8	Lost—In chimney to maintain draft—non-preventable	....	3,410,400
9	Lost—On account of air leakage in furnace and boiler setting—preventable	2,842,000	....
10	Lost—On account of air excess drawn through grates—preventable	2,842,000	....
11	Lost—Due to heating moisture in air and coal	....	426,300
	Totals	8,168,308	4,695,100
	INDIRECT FUEL WASTES HEAT ENERGY LOSSES		
12	Lost—Due to short circuiting of gases in gas passages of boiler	322,732	....
13	Lost—Due to soot on heating surfaces	1,126,561	....
14	Lost—Due to scale in boiler	1,452,293	....
15	Lost—Due to incorrect correlation of load to draft	1,116,800	....
16	Lost—Due to inability of boiler to reduce temperature of gases below that of the steam in boiler	....	1,280,907
17	Lost—Due to leakage of water and steam	216,685	....
18	Lost—Due to friction and radiation in steam pipes—non-preventable	....	216,685
19	Lost—Due to friction and radiation in steam pipes—preventable	866,742	....
20	Lost—With engine exhaust	....	7,627,331
21	Lost—Due to cylinder condensation and radiation	715,063	....
22	Lost—In friction at engine—non-preventable	....	119,177
23	Lost—In friction at engine—preventable	59,588	....
24	Lost—In transmission from engine to machine—non-preventable	....	231,000
25	Lost—In transmission from engine to machine—preventable	231,000	....
	Totals	6,107,464	9,475,100
	Grand Totals	14,275,772	14,170,200

Totals of all losses preventable and non-preventable . 28,445,972 B. t. u.
Delivered to the machine .... 554,028 B. t. u.

Received from mine .... 29,000,000 B. t. u.

Note—One ton of coal at the mine is assumed to contain 29,000,000 British Thermal Units. The items show where the losses occur and the relative sizes of same in average boiler and engine practice.

I use the expression "Build Up" because a really constructive process is involved. There is a place to begin, a plan to be pursued and an end to be attained. If you do not start in the proper way at the right place you will never have efficiency in your boiler room. And after you get efficiency if you do not follow the proper method you will not be able to keep it. Your plant will "back-slide" if I may borrow that term from "Billy" Sunday. I wish to make it very clear that it is one thing to "attain" efficiency and quite another thing to "maintain" it.

My statement that a quarter of the coal is needlessly wasted in burning may be challenged by some people. I shall not take it back; I have data covering hundreds of power plants and I can prove it. It is always dangerous to write a statement which on its face appears improbable. However reasonable your other statements may be the one that sounds extravagant may queer all of them. The reader is asked to accept that estimate of 25 per cent as applying to his own power plant until he has made the investigations suggested in this book and proved to his own satisfaction that his own plant is an exception to the general rule.

Is one quarter of your annual coal pile worth saving? It is a waste of good paper to print such a fool question. Of course it is. Every cent that the big pile of fuel represents was skinned from the dividend account. Just figure a moment. One thousand dollars thrown away in your boiler room must be replaced by another thousand earned from your business. That thousand dollars earned means something in volume of orders and volume of output. And if your total coal bill is only four thousand dollars per annum you are a relatively small bore institution. One large factory in Illinois made an actual saving of $73,000 the first year that the methods to be described in this book were employed in its boiler room and that year the plant earned its first profit.

The big industries of the country have made a discovery. They have learned that the profits of the present depend very largely upon the practice of economies and that the profits of the future will depend *entirely* upon such practice. They are going after savings in all departments while many

of the smaller manufacturers have yet to learn that there is such a word as "economy" in the dictionary. This waking up in the big industries is one of the reasons why big business is as big as it is and why the big fellows are eating up the little ones. I do not mean to say that all of the big manufacturing industries are really economical in the use of fuel. The majority are extremely wasteful. I do mean to say that the big enterprise is beginning to scrutinize its coal account and supervise its boiler rooms.

When our battleships made their celebrated trip around the world it was discovered by the fleet engineer that certain of the vessels were much more wasteful of fuel than others. There was nothing like uniformity in the coal consumed per knot steamed, even among ships that were almost the exact duplicates of each other. There was a difference of 20 per cent in the coal consumption of certain sister ships. Here was food for thought and the Bureau of Steam Engineering began thinking.

The following is quoted from an article by Lieut. Commander W. B. Tardy, U. S. N., published in the Engineering Magazine:

> "This recently inaugurated activity has already resulted in the installation of pyrometers and gas analysis apparatus on board all ships; has caused the building or improving of fire-room timing devices; has caused a study of combustion and firing problems which has led to a location and elimination of nearly all the air leaks in furnaces and boiler settings, the determination of the proper amount of coal for a charge at various speeds, the correct firing interval, the correct normal opening of damper and furnace and ash-pan doors when fires are not being replenished or worked; has demonstrated the saving of fuel possible by manipulating the same and ash-pan doors when coal is being fired.
>
> "On January 1, 1908, the average battleship knots per ton of coal fired was 2.88; on July 1, 1910, this average was 3.77 with ships 20 per cent larger on the latter date than on the former date."

The battle-ship now steams 31 per cent farther on a ton of coal than in 1908. This is equivalent to an actual fuel saving of about 24 per cent as an average for all ships. The improvement on some of the ships must have been far in excess of these figures.

I might go on indefinitely with these illustrations showing what it is possible to do and what is actually being done to decrease the primary cost of power. Some of the smaller plants furnish illustrations even more remarkable than those offered by the big ones.

In a small Ohio town there are two small factories.

They manufacture the same kind of product. The larger of the two plants burns one ton of coal per day and the smaller burns seven. In a Southern city there are two ice plants. One gets three tons of ice from a ton of coal and the other gets ten tons. The ten ton man is getting rich and buying more ice plants. Some day he will buy the piddling three ton plant and put it on a ten ton basis.

Power is the largest single item of expense in most manufacturing industries and fuel represents about 70 per cent of the total cost of power. And the price of fuel is going up. Nothing short of the discovery of a new source of power can stop the rising tendency of coal prices. You face the grim facts of sharp and merciless competition and of increasing fuel costs. The alarm clocks are going off in other establishments and it is time for you to wake up. If you sleep too long, waking up won't help you. The other man will be so far ahead in the race that you can never overtake him. Several bricks have recently been taken out of our tariff wall and every brick removed necessitates an increase in the efficiency of American production. Europe reached and passed a point years ago that we are just now approaching,—the point where industrial existence depends upon industrial efficiency. And, in the last decade, Europe has made longer strides in industrial progress and more of them, than the United States. It hurts our pride to admit it, but the facts are very obstrusive. In the metallurgical industries, for example, we are just now adopting methods that had become standard in Europe five years ago. The old world has carried the weight of its crushing armaments and has passed America in the rush for the world's markets. But there is comfort in the fact that American initiative coupled with the efficiency spirit that is now sweeping our country will get us away in time from the position of tail-enders.

Much just criticism has been leveled against the present propaganda of "scientific management". There is, in fact, a lot of "fish" in much of the efficiency talk and a great deal of "con" in much of the economy talk, especially where the "efficiency" and "economy" men have something to sell in the way of service or apparatus. The quacks and ex-

COAL PRODUCTION AND POPULATION INCREASE COMPARED

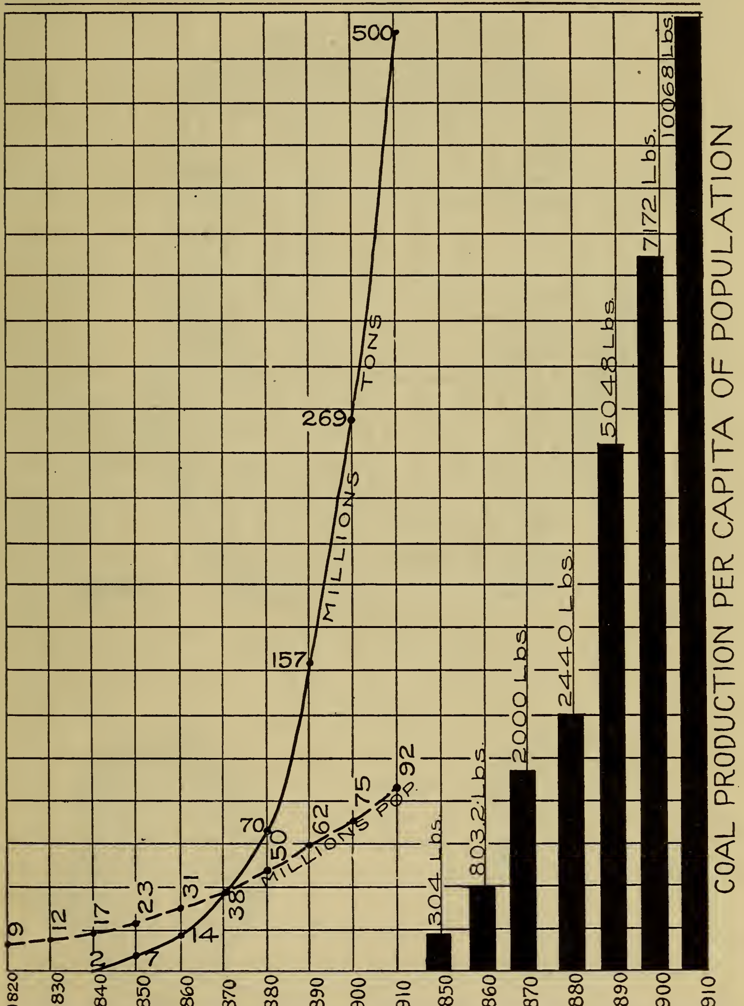

Chart showing why the cost of coal has risen and will continue to rise.

What you pay for coal

What you pay for wages, repairs and incidentals in the boiler room

What you pay for wages, repairs, supplies, etc., in the engine room

tremists are hurting this movement as they have hurt all others. And yet, notwithstanding the "fish" and the "con" of it, "scientific management" in its real and its broad sense is the most important industrial fact of the present century. One proof of this is that both big and little business are going in for it. "Scientific management" means more than "motion studies" and the speeding up of workmen. It means anything and everything that tends to make a dollar's worth of material, of time or of effort yield more results than it ever yielded before. A real revolution is in progress and it is good to be a participator in it.

There was a time when the manufacturers of this country were not interested to any serious degree in the subject of economy. Things were too new. Industrial development was too rapid. Competition was not intense. The material resources of our country seemed inexhaustible. We stupidly blundered on while all around us waste of every description held royal carnival. The soil was half cultivated and less than half cared for. Our great forests of splendid pine were ruthlessly destroyed. The sky was red with flaming gas wells in Indiana and Ohio. No one seemed to think that our rich soil would ever become impoverished; that the time might arrive when we could not live in wooden houses because there would be no suitable wood with which to build them; that our great stores of natural gas would ever become exhausted. We went blindly forward from year to year, wasting enough to feed and clothe half of Europe. The time has come to pay the piper and it is a mighty long bill that the gentleman is presenting.

I have referred to the general trend of the present efficiency movement because of its compelling importance and in order that what is to follow in this book may gain some emphasis.

Why is it that so much of your fuel is wasted? If that question cannot be answered we might as well ring off and hang up because all of our efforts will be useless.

Let us suppose that I visit your factory plant tomorrow. I call upon the Manager and he receives me courteously. I tell him that a quarter of his fuel is being wasted and he admits it. He is "busy" and he passes me along to the Superintendent. That individual is "busy" also. He is

worrying about the delivery on some big order. He sends me to the engineer and I know from his actions that he was glad to get rid of me.

I find the engineer with a Stillson wrench in one hand and a pair of pliers in the other. He is the "wet nurse" to everything electrical and mechanical about the plant. He "hasn't time" to supervise the boiler room. He is too busy supervising the apparatus that the boiler room serves to pay any attention to the thing that is doing the serving. Of course they waste coal in the boiler room, but look at the "dagoes" and "niggers" that they are forced to employ as firemen. The Manager is satisfied with that kind of service. The "old man" comes to the surface once a month and blows like a whale about the coal bill. Aside from this monthly disturbance, all is quiet along the Potomac. Our conversation is cut short by the engineer's telephone and I go to the boiler room. I tell the fireman that he is burning too much coal and he indignantly denies it. He has been firing boilers for twenty years and says he knows his business. But would I just look at the stuff the coal dealer is delivering?

And so I go to the coal dealer and ask him about it. He tells me that he is delivering the very grade of fuel called for in his contract, that it is good fuel and the plant has no kick coming. And thus I make the complete circuit of your establishment, like a kitten chasing its tail. I have made that circuit of power plants so many times that I am getting dizzy. Everybody lays it on the dog and nobody wants to be the goat. And that is "WHY YOUR FUEL IS WASTED."

A reform is necessary in your boiler room and in order to initiate it there must be an initiator. Absolutely nothing can be hoped for until somebody starts something.

I was talking a few weeks ago with a consulting engineer in the city of Philadelphia. He said: "I get plenty of work, charge high fees and suppose I ought to be satisfied but I don't like my business. The Manager of a power plant, in a fit of reform, employs me to make an investigation. I make a lot of recommendations, most of which if carried out would involve the expenditure of very little money. My

bill is paid promptly and I call again in a month to see how the plant is coming on. Not one thing that I have recommended has been done or ever will be done. I like to see my clients get some benefit from my services but in only about one job out of five are my recommendations actually carried out."

Every consulting engineer in the country who has recommended improvements in the power departments of factory plants will appreciate the viewpoint of the Philadelphia man.

Some one is primarily responsible for the fuel wastes in your boiler room. Let us proceed by a process of elimination and see if we can find the guilty man. We will start with the fireman.

What was he hired for? To make steam of course. There is nothing in your contract with the fireman that specifies anything about making steam with efficiency. One fireman will burn a lot of coal and make a little steam. Another will burn a little coal and make a lot of steam. There is that difference in firemen and you know it. What method have you of differentiating between your firemen and comparing the efficiency of one man with that of another? What steps do you take to insure that every fireman is an efficient fireman? Not a single step. You demand STEAM and you take efficiency like a tape-worm takes its dinner,—just as it is handed to you.

Your fireman knows that if he does not supply enough steam he will hear from headquarters. He knows further, that as long as he does supply enough steam, nobody will come near him to disturb him. What the steam that he furnishes may cost you does not concern him. Why should it concern him? If you are satisfied to pay the coal bills why should he worry about them? It is your coal and your money. Now, as a matter of fact, your fireman believes that he is an efficient operative. He even takes a little pride in the skill that he thinks he possesses. But he measures his efficiency by his ability to keep the arrow of the steam gage pointing at 100 pounds. He does not think of steam in terms of coal. He does not think of coal in terms of money. He places coal in the same category with clinkers

and ashes. It is just so much heavy stuff to be handled in the course of the day's work. And what other concept can you expect the fireman to have of your fuel pile? As fast as one pile of coal is burned another automatically takes its place. The coal is always there and the fireman is given a shovel and "carte blanche" to help himself to it.

We cannot blame the fireman for this quarter of your coal that he is wasting. We absolve him absolutely. He does the best he knows how and his performance is as good as the teaching he received. By the way, who taught your fireman? Some other fireman of course. Who taught the other fellow? And there you are. And there you will remain with your 25 per cent fuel waste until somebody shows your fireman that it is less work to shovel three tons of coal than it is to shovel four; that his labor will be reduced as his efficiency is increased and that if he would work his muscles less he must work his head more. Most firemen are afflicted with the hook worm and the sleeping sickness. "Do the minimum of work in the maximum of time and God bless pay day." This is the fireman's creed and for that matter it is the creed of almost everybody. It is human nature's creed and if you want efficiency anywhere you must learn how to deal with human nature. Human nature knows exactly how to deal with you.

In the last chapter of this book I shall tell you about methods that have been successfully used to convert the very lowest grades of men into expert firemen. I must not be understood to mean that a fireman is necessarily a low grade man. It is well to remember that a man's real status is not fixed by his environment or occupation. I respect firemen. I have taken my turn at the boiler furnace and I am not ashamed of it. On the contrary, I am proud of it. I know the fireman's point of view to a red hair and I know firemen. There are good men among them. They will listen to any man if they are convinced that his experience in the boiler room is broader than their own. It doesn't require much prophetic vision to do this bit of accurate prophesying.—The time will come when men will graduate from the engine room to the boiler room instead of the other way around as at present, when watch firemen

will receive better pay than watch engineers and when the highest salaried man in the entire power department will be the boiler room superintendent. That time has already arrived in some power plants. They have seen the universal mistake in arranging the personnel of the power force and they are now hitching up the cart to the right end of the horse.

Let us now proceed to determine the guilt or innocence of the engineer as respects your 25 per cent fuel loss.

An engineer is a man who is paid a mighty little for doing a mighty lot and sometimes earns less than his salary. The chances are that he rose from the position of oiler and never served an apprenticeship in the boiler room. When he learned engineering it was not considered necessary that an engineer should know anything about combustion. In those days the theory of combustion was left to the college professors and the practice of it to the firemen's union. The engineer now complains that he has little opportunity to post up on either the theory or the practice. He might find time for a little study on Thanksgiving and Christmas, but he is busy at the plant on those festive occasions, supervising emergency repairs. On Sundays he worships with his head inside an opened engine cylinder. I have known an engineer to do a 72-hour stunt in a power plant without a wink of sleep, a word of complaint or a whisper of commendation. Such things are not unusual. They are expected of engineers when the emergency arises and are expected by them. They are a part of the price that a man must pay for the privilege of being an engineer. I have said that I respect firemen. I respect engineers also, and I have a great many warm friends among them, but I cannot absolve the engineer for that 25 per cent fuel loss as I absolve the fireman.

Now Mr. Engineer we will go to the carpet:

1. What is the efficiency of your boiler furnaces?
2. What draft in your boiler furnaces will carry your load and burn the least coal?
3. Have you calibrated your boiler dampers and the main breeching damper?
4. Have you equalized the draft among the boilers?

5. How much air is leaking through your boiler settings?
6. When is an air leak an aid to efficiency?
7. Where are the air leaks that are injuring effiiciency?
8. How much too much air are your firemen permitting to flow through the fuel bed?
9. Do your firemen admit more air than is necessary at the furnace, either above or below the fire?
10. How much excess air from all sources are you heating and sending up the chimney?
11. How thick should the particular coal you are burning be carried on the particular grates you are using?
12. Are you using the coal best adapted to your conditions?
13. Are you using the grate best adapted to your conditions?
14. Should the coal you are using be fired dry or wet for greatest economy?
15. Is the grate surface just right for the highest economy?
16. How much and what kind of combustible is passing up your chimney?
17. What are the specific causes of the smoke you are making?
18. Is the low evaporation of which you complain, due to the boiler, the furnace, the coal or the fireman?
19. If you don't know why the evaporation is low, how in the name of Pluto will you proceed to increase the evaporation?
20. How much coal is your poor fireman wasting and how much more can your best fireman save?
21. Will you state, under oath, that the boiler headers are ALWAYS properly packed and the setting and baffling ALWAYS in proper condition before your boilers are put into service?
22. Aren't you ashamed of yourself if you are unable to answer all of the foregoing questions?

Now, Mr. Engineer, tell me candidly as man to man: Does not every one of those questions have a vital bearing on your employer's coal bill? If such is the case, does not your duty to your employer and your status as an engineer

require that you find the answers to those questions if you have not already found them? And should not every engineer who claims to have passed the kindergarten department of power practice be able to answer them? And didn't the Creator waste a lot of good mud in making an engineer who cannot answer them?

Let me tell you something: The demand for men who can go into big power plants and work out the answers to those questions is far greater than the supply. And the salaries that such men command are fixed by the law of supply and demand. There are not enough qualified combustion engineers to go around among the big plants that are calling for them. If you know of one that is running loose on the range, wire me his name and address. There are several jobs waiting for him.

Every engineer might be a qualified combustion man. Combustion engineering, as I shall try to show, consists in the application of ordinary horse sense to the every day problems of fuel burning. Any man with a fair understanding of boilers and furnaces and with a real desire to learn what constitutes economical combustion can qualify in a very short time as a practical combustion engineer. To acquire the theory of the subject would of course take some time longer. In the last year I have traveled over a large section of the United States and Canada. I have talked with hundreds of engineers and have been present at the meetings of many engineer's associations. Combustion is considered everywhere the very livest subject that can be mentioned. I quote the exact language of one engineer: "The time has come when the steam engineer must interest himself in combustion, otherwise engineering will not interest itself in him."

You can begin to "qualify" by commencing to study the boiler plant now in your charge. I know you are busy, but tomorrow you will be busier. There is only one way to do it. Wake up and get up. Gird up your loins, and go to it.

Just one thing more, before I talk to the General Manager. If you wish to institute any reforms in your boiler room, to make any repairs, to purchase any apparatus or

to do anything else for the improvement of efficiency that will require the consent of the Manager, go to him like a man and state your case like one. Don't be afraid of the Manager. He won't bite you. If you come to talk business he will take the time to talk business with you. If he wasn't that kind of a man he wouldn't be Manager. And he wants an engineer who knows what the plant needs and who has the intestines to ask for it when he wants it. Certain of the Power journals have been discussing the "timidity" of the engineer and in the opinion of the editors the reason why many steam plants fail to progress is because the Chief Engineer is afraid of the Manager.

And now, Mr. Manager, to what extent are you individually blamable for the waste of fuel in your boiler room? When I use the term "Manager" I refer to the executive who is the court of last resort on every important question relating to the power department. His official title may be something else. The man I am after is the man highest up who has anything to do with the power department and for purposes of identification we will call him the "Manager."

I have talked with your firemen and with your engineer about the waste in your boiler room and I have obtained very little satisfaction. The waste will continue until somebody starts something. My notion of a "Manager" is that it is part of his business to manage. When a reform is called for, he should either originate it or see that somebody else does some originating. The waste in your boiler room can be stopped by an order, an edict, an irade or whatevery it is that you issue when you want action. If your patience will permit a reading of this book to a finish I shall try to make good my strange claim that fuel wastes can actually be stopped by the fiat of the Manager. If you are in love with these wastes they will certainly continue. If you are not in love with them but keep mum about them they will just as certainly continue.

The captain is responsible for his ship and is held accountable for everything and everybody upon it. You are the captain of an industrial craft and you ought to sit up and take notice when the men of your command, heedlessly, carelessly and boneheadedly throw away your stockholders'

money. If you evince no interest in fuel economy you can't expect your firemen and engineers to sit up nights and worry about it. They are not stockholders in your institution. Interest will not originate in the boiler room. The higher up that interest starts the better. It will go down by force of gravity and stir up everybody below its point of origin. If you maintain your sphinx-like attitude on the subject of fuel waste, your plant will never enjoy the benefits of the most economical steam production because there will not be any such benefits to enjoy.

Treat the other departments of your factory plant with the same fine consideration that you show your boiler room and the sheriff will turn up in a short time with a placard and a tack hammer.

Every morning your firemen are handed a roll of money in the form of coal. You do not even count it when you hand it to them. You permit them to spend it according to their own fancy. You require no accounting from them. This is better treatment than you accord your wife. When Madam gets her allowance you know to a nickel how much you have handed her. She has to stretch it and get along with it or get up in the silent watches of the night and go through your trousers. Did you ever put a scoop shovel in her hands and turn her loose on your pile of bullion?

Every business day in the year a clerk from your office is sent to the bank to deposit the garnerings of your business. What would you do to that clerk if he should lose as many dollars each day on his way to the bank as you know your firemen waste each day in burning your fuel? If he lost a quarter of a dollar a day you would be furious about it. And yet you can talk of the waste of many dollars a day in your boiler room and be complacent about it. You reverse the telescope when you look at the boiler room and this makes everything down there look very small and very far away from you.

The money that your careless clerk loses on the way to the bank is not lost utterly. Somebody will find it and it may be returned to you. If not returned it may serve to buy food and clothing for some suffering family. But the fuel that your fireman wastes is lost forever. It is

gone absolutely without hope of recovery. Needless fuel waste can be properly classified as an economic crime, because it reduces our national resources and this in its turn affects everybody. When we apply that 25 per cent factor of needless fuel loss to the half billion tons of coal consumed in the United States annually, we have a conservation proposition of national importance.

A short time ago I called by appointment to see the Manager of an Eastern factory. We were to discuss the subject of his fuel losses and how to stop them. He broke the appointment to go to the golf links, but he was kind enough to leave a note of apology. I shall not call to see that man again. He can take his 25 per cent fuel loss or whatever his loss may be and stick it in his pocket.

A Chicago fireman was caught, several years ago, selling a few hods of coal from the bunkers of the boiler room in which he was employed. The weather was cold and the stoves in the Ghetto were hungry. His employer was justly indignant and the fireman was sent to the Bridewell. A few months later this same employer was shown by a firm of fuel engineers, how and why his other firemen were needlessly wasting more than 30 per cent of his fuel. He was "not interested." The loss itself concerned him less than the manner of the losing.

It is difficult to understand the average plant Manager's point of view as respects fuel economy. He regards his coal bill as a necessary evil and he considers preventable fuel waste as an organic disease, peculiar to the industry in which he is engaged,—a trouble that must be endured because he thinks it cannot be cured. And so in many cases it is impossible to interest him. He will tell you that he is not an engineer, that he cannot hope to understand engineering problems and that all such matters are left to his engineering department. But if you will go and talk with the engineering department you will find that he does not leave such matters in its hands. The Chief Engineer knows from experience about what his chances are when he makes a requisition for plant improvements. He must wait for the psychological moment to arrive before he makes his requisition. We must get on the leeward side of the Manager

and stalk him like a hunter stalks a lion. If he makes his approach at the wrong time or from the wrong direction his requisition will not be honored.

A Manager recently said to me, "It will be necessary for you to discuss that subject with our Chief Engineer. We leave all such matters to him." "Leaves all such matters to me, does he?" said the Chief. "In a pig's eye he does. If he only did leave them to me there would be something doing. Last week I went at the office with a requisition for a feed water thermometer. I was turned down. The old man said, we must 'economize.' I told him that was what I wanted to do and why I wanted the thermometer. I tried to explain that every ten degrees added to the temperature of the feed water meant a saving of one per cent in fuel and what do you think he said to me? He asked me if the thermometer would make the feed water any hotter. I told him that I couldn't heat water with a thermometer but that the thermometer would tell me where in thunder I was 'at,' that at present the only means I had of judging the feed water was by feeling the pipes. Did I get that $4.00 thermometer? I did not, and now I don't care what the temperature of the feed water is. I wouldn't turn my hand if the boilers were taking ice water."

Of course the engineer took the wrong position in the matter. If he could not get the co-operation of the Manager in securing economy he should have taken all of the economy he could get without co-operation. But he took the natural position and one that I find a good sized percentage of the engineers in steam power plants are taking.

If we must condemn the attitude of the engineer, how much more must we condemn the attitude of the Manager in that instance. If you want efficiency you must provide the means for producing efficiency. Pharaoh thought he could get bricks without furnishing straw and he fell down on the proposition. This happened 3,405 years ago, according to the chronology of Archbishop Usher, and yet in these late days and these enlightened times there are men who believe that they can put it over. The children of Israel did scratch around and produce a certain amount of

straw but it was expensive straw for Pharaoh. And a lot of engineers have gone down into their own socks for the money with which to purchase needed testing apparatus. Go and ask the manufacturers of steam engine "Indicators" about it. They will tell you that the Indicator worked its way into the power plant through the lean pocket books of operating engineers. Today the Indicator is considered a prime necessity in power plant practice and the plants themselves are actually buying them. Go and ask the manufacturers of Flue Gas Analyzers about it. They will tell you that a large percentage of their orders comes direct from the engineers of steam plants who are scrimping to buy the apparatus and who are paying for it in pitiful monthly installments.

You remember, Mr. Manager, the time that your engineer came to your office, cap in hand, and asked you to buy something that he needed to improve the efficiency of the boiler room. You turned him down rather gruffly and he proceeded to "beat it." You haven't seen him since and he is not likely to bother you again. Nice encouragement, that, for an employee who felt that he was risking his job in asking you to spend a few dollars in your own interests. I am sure you would have respected him more had he stood his ground like a man and demanded the thing that his judgment told him he needed. I am not your employee and I am not the least little bit afraid of you,—hence I am shoving these few facts right down your throat into your gizzard.

I do not mean of course that you should buy every fool thing that the power department asks for and that is guaranteed to improve efficiency. Murder! No. That would be as reprehensible as your present practice of buying nothing. You have bought too much stuff in the past that proved to be junk and that is one thing that ails you. You now class everything that is offered in the same category. For example, when the smoke inspector was after you, you afflicted your boilers with patented steam jets at a cost of about $200 apiece. You didn't know that these devices were condemed by engineering authorities nearly 50 years ago. And when the steam jets failed, you paid another

man about $200 per boiler to surround your fire box with air ducts. You didn't know that the air ducts were tried and found guilty before steam jets were invented. You didn't know that more than 1,700 patents have issued from the United States Patent Office, covering steam jets, air ducts and other fake furnace contrivances all of which violate the basic requirements of economical combustion. You have regarded combustion as a mystery and you have neglected to inform yourself. Hence you have bitten at the fakes and been bitten by the fakers. Hence you place the good things that you ought to buy in the same category with the bad things you have purchased. In the later chapters of this book I shall try to show you what a marvelously simple thing it is to secure economical combustion. I shall give you the data that will enable you to choose among the host of things, good, bad and indifferent, that are offered for the use of your boiler room. And the next time that you are asked by your engineer to buy something for power plant betterment, don't dismiss him but make him come across and show exactly how and why the thing that he wants is going to improve conditions. If he can't show you and prove his case, don't buy it. If he does show you and you don't purchase, give him a mighty good reason for your refusal and ask him to come again whenever he has a suggestion to offer. Give your power department the same business treatment that you give every other department.

And so, Mr. Manager, when we submit this question of WHY YOUR FUEL IS WASTED to fractional distillation and ultimate analysis, we find that you yourself are primarily responsible for all of the trouble. We are forced to condemn you without benefit of clergy. You are the "nigger in the wood-pile," the "woman in the case," the "casus belli" and the "primordial germ" of all of the fuel wastes in your boiler room. If you don't take a stand for economy we might as well throw up the sponge and all the rest of the groceries. If we can get you started and keep you going we can inoculate everything on two legs around your factory with the germs of economy and the anti-toxins of waste. We can even make the girls in the office remember to turn out the electric lights when

they are not needed. We can go to the very limit in everything that affects the cost of heat, light and power. We can't do a blamed thing if you won't back us and help us. You are in a position to say that the things which *should* be done, *must* be done. If your engineer is incompetent or remiss in his duties, put him on the toboggan slide and get another one. And the next time that you hire a chief engineer look at his head before you look at his hands. If he is short a few fingers it doesn't matter, but if he is short in the noddle you don't want him. If he doesn't know to stop fuel wastes you can't afford him.

And now, having blackguarded everybody to my heart's content, let us get down to the brass carpet tacks of the furnace efficiency question. In the next four chapters I shall try to hold up each individual item of fuel waste and visualize it so that you can see it. And for each item of preventable waste I shall offer a specific remedy. I want the Manager, the Chief Engineer and the Firemen to go with me to the boiler room and stay with me through those four chapters. I shall have something to say to each of them. And what I shall say will apply to your plant, no matter whether you have hand-fired furnaces or automatic stokers,—no matter whether you burn coal, oil, gas, sawdust or buffalo chips. Combustion is combustion. It makes very little differences what the fuel is or what the purpose may be for which the fuel is burned. The same general principles apply in all cases.

It is a short distance, as the crow flies, from the manager's office to the boiler room, but it is a dickens of a long road by the route that the manager travels.

CHAPTER II.

HOW YOUR FUEL IS WASTED.

Waste is the "black beast" of every manufacturing business. It has more lives than any cat that was ever kittened. We can't kill it. We can only fight it and we must be continually on the alert if we would keep the brute out of the establishment. Eternal vigilance is the price of economy.

As I tried to show in the first chapter, fuel economy waits for somebody to start something. After things are started economy demands a very persistent follow-up and a careful attention to details. Fuel economy depends upon little things and many of them. I suppose the same thing may be said of economy in any other relation. However that may be, the statement applies with particular force to all of the economies that relate to the production of power.

The first step toward fuel economy must be taken in the field of psychology by the association of ideas, rather than in the field of engineering. The Manager must change his concept of the power plant. He must get it into the factory class and associate it with ideas of money earning. He will then apply to his steam plant the same business methods that he uses in his office and factory. And if he does this the preventable wastes will disappear and the boiler plant will begin to really earn real money.

Now let us try the "association of ideas" and see where it leads us. Suppose your factory is losing instead of making money. What do you do about it? You seek to discover the causes of the loss and you lose no time about it. Your cost of production may be too high, your sales force may be inefficient or you may have been unwise in the extension of credits. You will go hunting for reasons and causes and you will keep on hunting until you find them. As a manufacturer you have two general problems to consider, viz.: How to transform the raw materials into the

finished product with the least possible expense and how to transfer the finished product from your factory to the consumer with another least possible expense. These same problems present themselves when you consider the manufacture of steam for your own uses and a third problem arises from the fact that you are both producer and consumer. You want to make the steam go as far as possible after you have manufactured it. Accordingly if you think of economy twice in connection with your factory product, you must think of it three times in connection with the product of your boiler room.

Most manufacturers regard the entire power problem as a thing of mystery. Most engineers regard the combustion problem as a baffling proposition. There is no mystery about either fire or water. We bring the two together and the result is steam. There is no more mystery about a furnace and a boiler than there is about a stove and a tea-kettle. The process in each case is exactly similar to that in the other. It consists in getting the heat out of the fuel and into the water. There are accordingly just two general problems to be considered in the economical production of steam, viz.:

1. Are you actually using all of the fuel?
2. Are you putting as much of the generated heat as possible into the boiler?

Burn all of the coal you buy and use all of the heat from the coal you burn. That is all there is to it. And after you have made the steam and developed the power, don't waste them. These propositions are self-evident and I state them more for the purpose of outlining the discussion that is to follow than for your information.

You are running a steam factory and selling its product to yourself. You are making steam at a loss and business gumption tells you that it should be made at a profit. Steam and power are commodities just as much as soap or plows or beer or pianos. You can go into the market and buy your steam and power from the central station. The difference between the market price and the cost of production in your own plant expresses the loss or profit of your steam factory.

The central station makes power to sell and you make it to use. It treats power as a merchantable commodity and sells it at a profit. You treat power as an incident and you produce it at a loss. The central station looks after the little big things that affect the cost of power production and you permit your power house to look after itself. And I have been in central stations that were wasting a quarter of their fuel. They were able to stay in business because some of the isolated plants around them were wasting much more than a quarter.

Power, like any other commodity, can be manufactured cheaper at wholesale than at retail. The central station has that economic advantage over the isolated power plant but against this advantage are certain handicaps which tip the scales against it. It costs the central plant something to get and keep your business. It must run transmission lines and maintain them. All these items, which do not afflict the isolated plant, must be added to the central station's cost of power and to its total cost must be added a safe margin of profit. The "wholesale" explanation does not explain everything. If isolated plants were as economical in the use of fuel as they might be, the central station would find very poor pasture. The central station makes money because the isolated plants waste money. Now before you contract for outside power let us see what can be done to place your own steam plant upon a paying basis.

The raw materials out of which steam is manufactured are fuel, air and water. Air costs nothing and in order to simplify the work before us we will assume that water costs no more than air. The cost of water in the steam factory, may, of course, be considerable. The only costs we shall consider are those directly and indirectly related to the fuel, which we will assume to be coal.

Let us suppose that we buy a ton of coal at the mine and that the heat value of the fuel is 14,500 British thermal units per pound. There will accordingly be 29,000,000 heat units in our ton of coal. As each heat unit represents 778 foot pounds of energy we find that we have purchased considerable latent dynamics. If the energy in a few pounds of that coal should be explosively released in your boiler

room there wouldn't be enough left of your factory plant to make a grease spot on the horizon. The process of steam power production consists in taking this energy out of the coal and making it do useful work in the factory. If we could only reach the switchboard with all of the energy that we buy at the mine the power bill would not be a serious matter. The average steam plant wastes 98 per cent of the energy between the mine and the machine. If a ton of coal costs $3.00 we get our money's worth on a nickel and a fraction of a cent. We begin to spill the energy out of that ton of coal as soon as it is loaded into the railroad car at the mine and we keep on spilling energy whenever we change it from one receptacle to another or transform it from one condition to another. More than half of the energy waste in the average power plant is preventable, so that if all of the losses could receive proper attention we should be able to make a half a ton of coal do what a whole ton had been doing before.

The table presented in Chapter I shows about how the losses take place between the mine and the machine in your factory. It shows exactly where we must look to make the fuel savings.

The first spill of energy takes place when the coal is exposed to the weather. It oxidizes very slowly. The University of Illinois has conducted extensive experiments to determine the effect that "weathering" has upon coal. The loss was found to be most rapid during the week or ten days first following exposure after mining. The waste thereafter, while very slow, continued indefinitely. The loss is greater with the smaller sizes of coal owing to the fact that a proportionately greater surface is exposed to the action of oxygen as the lumps of coal decrease in size. The loss in covered bins was substantially the same as in open bins. It was least when the coal was stored under water. In its bulletin on the "Weathering of Coal" the University says:

> "In the coals that have been tested, 1 per cent is about the average loss for the first week and 3 to 3½ per cent would cover the loss for a year, although in some cases the loss was found to be as high as 5 per cent in a year."

It is probable that the figures given above are away in

excess of what would be expected in commercially stored coal. It is obvious that only those portions of the coal pile that are actually exposed to the weather will be influenced by atmospheric action. Chemical change is, however, likely to take place at the interior of the coal pile. One of the objections to coal storage is the danger of heating and spontaneous combustion. These dangers are increased when the coal is in a finely divided condition and contains sulphur or pyrites of iron. When coal heats spontaneously there is a loss of heat energy equal to the actual heat generated and when it ignites spontaneously the loss may be total.

Unless there is some good reason for the storage of coal in quantity it is best to keep as little of it on hand as possible. The storage place should, of course, be located with reference to convenience and ease of transferring the fuel from the bunkers to the furnaces. My observation has been that in many power plants a change in the location and arrangement of the bunkers would result in a material saving of money. Labor, like coal, represents money, and it is often more difficult to handle than the inanimate fuel. The big central station installs coal and ash handling machinery which cuts down the cost of power by reducing the cost of labor.

It is not practical to store coal under water and so I have set the loss due to weathering in the column of non-preventable wastes. I have placed this loss at 1 per cent, or 290,000 heat units, and we won't cry about it because there are enough losses ahead of us to weep over.

To get any good from coal you must put it in the furnace and burn it. How much of your coal is wasted in handling? A lot more than you imagine. Take a walk through your boiler room and around your boiler house and see for yourself. You will find raw coal everywhere. Feet and wheels have ground it into a powder. You will find coal in the ash pile that never saw the inside of the furnace. If there is coal in front of the boilers when the fires are cleaned some of it will get into the ash and be carried to the dump. Some of the ash will get into the coal and with it go into the furnace. The result will be clinkers,

which make work and waste fuel. The loss in handling is very small as compared with some other losses. It is large enough to be considered and it can be cured if you will see that better housekeeping methods are adopted in your boiler room. I have placed the loss in handling at 1 per cent of the fuel. It is less than that in some plants and much more in some others. The reader will remember that in all of the figures presented in this book the conditions that obtain in average power plants, big and little, are being considered.

Now, how will you induce your men to be more careful in the handling of your fuel? By impressing the fact upon them that a lump of coal represents money. The fireman, as I have already told you, does not think of coal in terms of money.

I was walking through the boiler room of a power plant not long ago in company with the Manager. We stopped to watch a fireman who was loading up a wheel-barrow with clinkers and ashes. When the man's back was turned I dropped a nickel at his feet and then called his attention to the coin, with the remark that somebody was very careless with money. He lost no time in putting that nickel in his pocket. Visions of a foaming tin bucket rose before him. I said to him, "Man, there must be something wrong with your eyesight. I saw another nickel go into that wheel-barrow with the ashes." He dumped that barrow of ashes on the floor and pawed all through it. He didn't find the money. I said, "Bring me a pail of water and I will show you how to find money in ashes." If there is anything that will make coal and coke stand up in a pile of ashes it is a douche of water. I drenched the ash-pile and then picked it over. I got a respectable looking pile of coke and coal from the ashes. It was unnecessary to explain to the fireman what I meant by money in the ashes, or to explain to him that the money he was throwing away belonged to the Manager of the plant who stood beside me. The next time it rains take your firemen to the ash dump and give them an object lesson.

You are not burning the coke that goes through your grates with the ash and you are not burning the combusti-

ble gases that go up your chimney with the smoke. When you have looked around the boiler room and the boiler house, when you have looked at the ash pile and the chimney you will have some idea of the fuel that is being wasted without being burned.

We must expect to find some coke in the ash and you need not be frightened if you see some smoke coming from the chimney. Smoke means waste as we shall see later on, but not in the way that is popularly supposed. The soot of the smoke cannot in the very worst circumstances exceed two per cent of the carbon in the fuel. There may be a great deal of smoke going up the chimney and very little combustible, or there may be a great deal of combustible and very little smoke. There may be combustible gas and considerable of it in the entire absence of smoke. These things will have consideration in a later chapter.

You must expect to find some coke in the ash. It is impossible to burn coal for power purposes and avoid all waste through the grates. It is possible to keep the loss down to a minimum. In order to know what the waste really amounts to you must first know how much ash the coal itself contains. If you have been having your coal analyzed you will know how much ash the raw fuel carries. In the absence of a laboratory report you will be able to get quite accurate data in the following manner. Weigh all of the coal burned during a day's run and all of the ash and clinker resulting. These weights should be taken every day, but that is not the practice in the average power plant. Take a couple of scoops of ashes from each barrow load as it is removed. Douse these ashes with water and have them carefully picked over. On weighing the coke and the ash proper you will have the data from which the actual "ash waste" can be closely computed. If the loss does not exceed one per cent of the combustible of the coal you are doing well. If you are wasting four or five per cent, as is likely to be the case, your firemen must mend their ways.

Much of the waste detected in the ash pit of the boiler furnace is due to the improper use of fire tools. The slice bar is abused almost every time that it is used. Watch your fire-

man when he uses it. He will run it along the grates under the fuel and then employ it as a pry to tear the fuel to pieces. This mixes ash with incandescent carbon. The ash fuses and clinkers result. The purpose of the slice bar is to cut or "slice" the fuel away from the grates and to cause the fine ash to fall through the grates. Under no circumstances dig up the fuel with it. Under no circumstances use it unless the condition of the fire calls for it. The fireman can tell from the dark spots in the ash pit when and where the fire needs slicing.

Why do you burn coal under a boiler? To make steam, of course, by passing the heat from the furnace through the metal work of the boiler where it can get action on the water. Now, suppose that you cool down the hot gases before they reach the heating surfaces of the boiler, or that you cool them by outside influences while they are in contact with the heating surfaces of the boiler, or that you hinder the heat in some way from passing through the metal to the water, or that you permit some of the heat to escape before it has a chance at the boiler—you will lose just that much heat, won't you? And you will have to burn just that much more coal to replace the heat that has been lost.

Burn as much of the fuel as possible—i.e., waste as little as possible on the floor, in the ash and in the chimney.

Use as much as possible of the heat resulting from the fuel that you actually burn.

Do these two things and you will get all of the steam that it is possible to make with the furnace and boiler equipment that you have.

You probably lose about five per cent of the heat generated in the furnace through radiation from the furnace and the boiler setting. You could stop four-fifths of this loss by proper insulation. One or two inches of asbestos plaster, covered with canvas and the canvas covered with paint, makes a serviceable overcoat for a boiler setting.

This overcoat will serve the double purpose of keeping the heat in and the "cold out." You apply weather strips, storm sash and storm doors to your houses. Use the same degree of common sense with your boilers. The radiation loss is a small circumstance compared with that due to ex-

cess air and the "overcoat" will reduce the excess air. By "excess air" I mean the air that is taken into the boiler furnace or into the passes of the boiler in addition to that actually used in the processes of combustion. Suppose we take 100 cubic feet of air into the boiler furnace and use all of the oxygen in that air to produce combustion, and suppose that we actually produce complete combustion under such circumstances. The furnace would be operating under ideal conditions and with the theoretical air supply. The furnace temperature would be extremely high—close to 4,500 degrees Fahrenheit. Nobody has ever seen such conditions in a coal burning furnace. I am only supposing them. In burning a solid fuel it is quite impossible to maintain uniform conditions throughout the fuel bed. The coal will be a shade thinner in some places than in others. Little cracks and fissures will form in the fuel as it settles on the grates. These thin places and cracks oppose less resistance to the passage of air than the other portions of the fuel bed and they get more than their share of it. Hence it follows that in burning coal or any solid fuel we are forced to entertain some excess air in the furnace. If we cut out this excess some portions of the fuel bed will not get enough air and the result will be incomplete combustion. The gas CO will be formed and flow up the chimney CO is the principal constituent of the illuminating gas which is piped to your residence at $1.00 per thousand cubic feet by the gas company. You can't afford to send a valuable gas like that up the chimney.

You can get complete combustion of coal in the boiler furnace and not use more than 40 per cent excess air. If the coal runs high in ash it will be necessary to use more air, and if you are burning oil or gas under your boilers you can reduce the 40 per cent excess. In the next chapter I shall tell you how you may determine the exact percentage of air excess as well as the exact percentage of combustible CO.

A brick is a porous thing. Throw a dry one into a pail of water and watch the bubbles as the water enters the pores of the brick and drives out the air. Weigh the brick before it goes in and after it comes out of the water. Now, remember that there is a partial vacuum on the inside of your boiler

setting when the furnace is in operation, and atmospheric pressure on the outside of it. Every pore in every brick is busy trying to satisfy that vacuum. More cold air will flow right through those bricks in your boiler setting than you imagine. If you will glue an air-tight box to your boiler setting and connect a sensitive differential draft gage, such as is shown on another page of this book, with a tube running into the box you will find that the suction of the chimney is communicated through the pores of the brick and that this will be indicated by the movement of the liquid in the draft gage.

The 40 per cent excess air that you are forced to entertain reduces the furnace temperature about 1,500 degrees Fahrenheit. You want no more of that sort of reduction than you are forced to stand. Hence you want to stop the infiltration of air through the brick work. The overcoat will stop it. If it is not the season for "overcoats" in your power plant you can stop the air seepage by "sizing" or painting the brickwork. The paint will make the boiler house look more home-like to the fireman and you will get a dividend on your paint investment every time the fireman throws in a shovel of coal.

The cold air loss due to infiltration through the brick compares with the other cold air losses your plant is suffering as a sneeze compares to a Panhandle Norther. We are right on the track now of some of the old "he" losses that are making a joke of economy in your boiler room.

The chimney is constantly pumping air and gas from your furnace and boiler. The partial vacuum created will cause air to flow into the furnace and the gas passes of the boiler wherever and whenever it can get in. Now if there is a crack in the brick work that looks suspicious, try that crack with a candle flame. If there is an inward draft of air the candle flame will indicate it. A tallow candle or a kerosene torch is one of the most important pieces of testing apparatus that you can have in your boiler room. Whatever else you neglect to get, don't neglect the torch or candle.

In the table of losses preceding I have fixed that due to air leaks in the furnace and boiler setting at 10 per cent of the heat generated in the furnace and this is a conservative esti-

mate for the average power plant. I have seen savings of 20 per cent made by stopping up the rat-holes in the settings of water tube boilers. I have known a plant to go from three boilers to two after the leaks were stopped. And I have the very dickens of a time making some engineers believe that the leaks in their boiler settings really amount to something. I have to take a gas analyzer and prove it to them by actually measuring the volume of air that is flowing through the cracks as compared with the volume that is used to burn the coal. They seem to think that you can make steam with cold air.

Engineers often say to me, "What's the use of plastering up cracks in the brick work? They will not stay plastered. The stuff will shrink when it dries and fall out." Of course it will. Therefore, don't "plaster" the cracks. *Calk* them with something that will not fall out. Make a very thin mixture of fire clay and stir cotton waste into it, first pulling the waste apart so that every fibre of it will be covered with the clay. The waste being dry, will pick up a lot of the clay. Next sharpen a piece of board for a calking tool and with it drive the clay-coated waste into the crack. Fill the crack full and drive the stuff in tight. It will stay there until the setting falls down and the cows come home. This can be done while the boiler is in operation so that you can begin to get financial returns on your clay and cotton investment without waiting for the boiler to be shut down. Two or three hours work and a dollar's worth of material will stop a lot of cracks. There are cements and other materials on the market made especially for the purpose of permanently sealing up a brick boiler setting. They are somewhat superior to the paint and the fire-clay that I have here recommended.

You must not assume that any crack you may find anywhere about the boiler setting is not conducting air to the heating surfaces of the boiler. You don't know where that crack leads to and the only safe thing is to try the candle flame on it. And remember that a crevice between an "I" beam or a stay and the brick work may lead to some hidden avenue that will carry cold air where it will do a lot of damage. And don't forget to inspect the brick work on top of

the boiler. Don't make a casual inspection. Make a thorough one. I found air leaks on one occasion, aggregating one and a half square feet, at the rear of a marine boiler of the "B. and W." type when the engineers of the ship were willing to make oath that the setting was air tight. On another occasion I won the cigars by finding more than 20 sizable air leaks in the brick work of a "B. and W." boiler in a stationary plant. The engineer had just finished calking the brick work of that boiler and he thought it was air tight. I had had more experience in the air leak business than that engineer and I knew where to look for trouble.

You are not through looking for air leaks when you have finished inspecting the brick work of the boiler setting. Inspect the "metal work". I assume that in going over the brick work you will have seen to the clean out doors, the blow-off pipe, etc. This is not the "metal work" that I refer to. You are not through with the work of inspection until you have tried the candle at the boiler headers. A boiler of the "B. & W." type is an admirable steam generator and it passes my understanding why the manufacturers have not devised some practical means of preventing air from flowing in around the front headers into the first pass of the boiler. The boiler doors are supposed to keep cold air away from the headers, but in most cases they don't do it. Show me a "B. & W." boiler and I will bet five to one that I can find some place about the boiler doors where the draft will suck out the flame of a candle. An inflow of cold air around those boiler doors is not only bad for efficiency, it is bad for the boiler headers. Those headers were properly packed, I suppose, when the boiler was delivered by the builders. The trouble is that the packing has fallen out and nobody has thought worth while to replace it. When the engineer's attention is called to the situation at the boiler front he is surprised. He had supposed that the packing was in proper condition and that the doors were tight. It is bad practice to "suppose" anything about a steam boiler. The trouble with the boiler door is that it will warp, that the catches will not draw it into proper position, that one or more of the catches may be broken, or that some careless somebody will neglect to see that the door is really closed in

the way that the builders intended. In one case that came under my observation an actual fuel saving of 20 per cent was effected by packing the front headers of a battery of "B. & W." boilers. In that instance over 200 per cent excess air was flowing around the boiler headers into the first pass.

Excess air is the greatest of all causes of fuel loss. The tax exacted by it exceeds the sum of all the other taxes combined that are levied by the wasteful furnace upon the suffering coal pile. I took the trouble to examine the logs of all of the tests made by the United States Geological Survey at its exposition testing plant in St. Louis. The excess air losses as shown by those tests were ten times the losses due to incomplete combustion. If you want to make a home-run for efficiency begin on excess air.

I absolved your fireman in the last chapter and I absolve him again. He is not responsible for the physical condition of your boiler plant. He takes the boilers as he finds them in the morning and he fires as he sees fit during the day. He hasn't time to calk air leaks and he isn't hired for that purpose. You can't make steam with a sieve. If you will take a candle and go over your boiler setting you will find that you are trying to do so. You could go all over a boiler setting in the time that it has taken to read this Jeremiad on air leaks. After you stop the leaks you will find that the boiler steams more easily and that there is more draft. Cold air kills draft. You may now have to check the dampers to keep the safety valves from blowing.

An Eastern factory had great difficulty in getting enough steam from its three return tubular boilers. They were actually contemplating the installation of a fourth boiler. The engineer bought five cents worth of tallow candles and went after the air leaks. When the cracks were calked there was plenty of steam. Now most men would have stopped at this point because most men are satisfied when there is enough steam for the factory. They look upon the boiler plant as just something to make steam, not as something that should be made to earn a profit like the factory proper. This engineer had been inoculated with the efficiency germ and he wasn't satisfied. Efficiency is the most appetizing thing. When you get a taste of the real article you can't get enough

of it. In March, 1911, the plant in question was burning coal at the rate of 2,300 tons per annum. It is now burning coal at the rate of 1,000 tons per annum and turning out as much product as in 1911. This is a reduction of 56 per cent and if you don't believe the story you don't have to. The improvement was due to the efficiency germ that got into the engineer's system.

When the engineer had stopped up all of the air leaks he could find he said to himself, "Are there any other places where cold air can get in to cool off the hot furnace gases?" This question led to the following conclusion:

"When the furnace doors are open cold air will rush in and cool off things. This is bad for the coal account and it is bad for the boiler, as the cooling off and heating up mean expansion and contraction, which in turn lead to leaks. Therefore, it is essential that the furnace doors should be open for the shortest periods possible. To this end the firemen must have the coal where they can reach it quickly and the doors must be fixed so that they can be opened and closed in the shortest possible time, and with the least possible effort. The firemen must understand that "time is the essence of things" when the furnace doors are open.

These conclusions led to certain minor rearrangements and the firemen were speeded up to an appreciable degree. The engineer then remembered having read in a book somewhere that a coal burning furnace can be most economically operated with about 40 per cent excess air—that anything in excess of 40 per cent leads to needless waste through a needless chilling of the gases. His line of reasoning led him to a further conclusion, viz.—that cold air could get into the furnace through a hole in the fuel bed, also that there must be some relation between the draft over the grates and the resistance of the fuel on the grates. In other words, too strong a draft and too thin a fuel bed will lead to excess air and the excess taken in this manner is just as damaging to efficiency as an excess taken in any other manner.

He now saw that an apparatus for measuring the excess air carried by the chimney gases would be essential before he could go further with his investigations Without such apparatus he would never know how near or how far he might

be from that dead line of 40 per cent excess. Moreover, he could never expect to standardize the firing practice in his boiler room until he had gages to measure the drafts over the fire as well as an apparatus to measure the excess air.

On inquiry he learned that the very apparatus he required had been on the market and in use in power plants for many years, moreover, that he could take his choice among several different styles of such apparatus and largely suit himself in the matter of price. He accordingly purchased a draft gage for each boiler furnace and one flue gas analyzer.

While waiting for this apparatus to arrive the engineer became curious about the heating surfaces of his boilers. On the Sunday following his first investigations one of the boilers was shut down and he made an examination of that boiler. It had been customary theretofore to just wash the boilers out when they were down and to rely upon the saving offices of some physicking boiler compound. There was a whitish incrustation on the boiler tubes and a cleaning tool was obtained on the gamble that the innocent appearing white stuff might not be as innocent as it looked. It is sometimes impossible to tell by looking at a boiler tube whether the scale is as thick as an egg shell or as thick as a pancake. When the cleaning tool was through with the guts of those boilers it had jarred loose about a wagon load of scale and the engineer ceased to wonder why his boiler efficiency had been suffering with the belly-ache.

The heating surfaces of boilers are made as thin as safety will permit, because the thinner the metal the more rapidly the heat will be transmitted to the water. Now the conductivity of steel is about five times that of lime scale, so that a tube with a quarter of an inch of scale upon it will give heat to the water no faster than a steel tube an inch and a quarter thick. Boiler tubes are about an eighth of an inch thick so that one-fortieth of an inch scale lessens the factor of conductivity to the same extent that it would be reduced by doubling the thickness of the tube. Any quantity of scale is bad for economy.

The cleaning tool also dislodged quite a lot of carbonaceous scale from the fire side of the tubes so that after the

cleaning was finished both the gases and the water were in contact with the clean metal. The effect was extremely pronounced. It had been formerly difficult to get sufficient steam. The stopping of the air leaks had helped amazingly. The cleaning of the heating surfaces gave such an impulse to the boilers that there was now too much steam and one of the boilers was laid out of service.

It is quite superfluous to say that the boilers in that plant are now cleaned of soot and scale accumulations so frequently that the heating surfaces are kept in proper condition to perform their functions all of the time.

I cannot pass this subject without a word of solemn warning about the injudicious use of boiler compounds. In most cases they do more harm than good and in some cases they have been the originating causes of destructive boiler explosions. Your engineer is liable to fix up some home-made preparation and put it in his boilers if he is not cautioned. I have actually known muriatic acid to be used. In the back woods districts engineers still put stable manure in the boiler on the presumption, I suppose, that it will be sure to increase the horse power. Don't buy a stock boiler compound under any circumstances. It may prove to be the very thing you should not use. Never use any compound until the water you are using has been analyzed and a compound especially prepared for that water. Whatever compound you do use, inspect the tubes whenever the boiler is down and clean them whenever necessary.

When the gas analyzer and draft gages arrived a further surprise was sprung upon the coal account. It was found that instead of an air excess of 40 per cent the furnaces were taking over 300 per cent. The cooling effect of that much air offset the heat derived from about one-quarter of the coal burned. It did not take long to find the reason for this excess air. The fires were too thin on the grates and the firemen were not careful to distribute the coal evenly over the grates. Thin spots and holes were the result, through which excess air was pulled by the draft of the chimney. After a little experimenting the proper thickness of the fires was determined and marks were placed upon the liners of the fire doors to guide the firemen. The effect

of anything that was done to increase or decrease the air excess could be determined with the gas analyzer in less than a minute. This made it possible for the engineer to give the firemen some object lessons. He showed them the effect of every little crack and rat-hole in the fuel bed. He was even able to measure the exact volume of air flowing through a given hole in the fire and to tell the firemen in terms of coal how much saving the closing of that hole represented.

The two boilers now made more steam than the plant could use, whereas the factory had been limping with three boilers before the engineer got busy with his tallow candles.

The second boiler was then cut out of service, but the load proved too much for one lonesome boiler. The grate surfaces were then reduced by shortening and narrowing the grates under the two boilers. The engineer went as far as he thought it was safe to go in reducing grate areas and still there was too much steam. He then reduced the rate of fuel consumption by reducing the draft. He placed a draft gage on each boiler furnace and equalized the draft by adjusting the individual boiler dampers. In this way the two boilers were made to work under the same draft conditions and the combustion relations were reduced to a common denominator. The fireman could now treat the two furnaces exactly alike. What applied to the one applied to the other. There were the draft gages to show him when he had exactly the right draft and there were the marks on the door liners to show him when the fuel was of just the right thickness on the grates. The fireman could now be reasonably certain at all times that the air excess was close to 40 per cent and that he was working the furnaces at just about the top notch of efficiency.

Now it is one thing to show a fireman what to do and how to do it. It is another thing to have him do it when nobody is watching. Everything about the boilers had been checked up and the fireman knew exactly how to get efficiency and a lot of it. It was now just a matter of checking up the firemen. A gas collecting device was placed on each boiler so that at the end of a watch it could be known in a few minutes exactly how much excess air had flowed across the heat-

ing surfaces of the boilers during that watch. The engineer now had the means of exactly rating the efficiency of each fireman.

The result of all of these things was a saving in that plant of more than 56 per cent of the fuel. And the happiest people about the plant were the firemen. They were now handling less than one-half of the coal and ashes that they had been handling before. They had learned that a little mental exercise will save a great deal of manual labor. Skilful firing, like skilful anything else, requires some thought and a reasonable amount of attention to certain details. And when a man knows that he is skilful he begins to take pride in his skill. This is human nature—the same human nature that I have mentioned before. And, Mr. Manager, take advantage of human nature wherever you can. If you don't do it human nature will take advantage of you.

The table, Chapter I, shows about how the other losses between the mine and the machine occur. I have touched to some extent upon all of the losses with which we are concerned in this book, except that due to soot deposits upon the heating surfaces of the boiler. This will receive attention in its logical place in a later chapter.

Take off your hat to the next load of coal that is delivered to your bunkers. It contains a quantity of energy that is quite beyond our powers of comprehension. Remember that you are wasting 98 per cent of it. I have in my desk a loaded cartridge for a modern high-service rifle. It contains a pinch of carbon in the form of smokeless powder. There is enough sleeping energy there to strike a blow of more than a foot ton at a distance of one mile. There are twenty-nine million heat units* in your ton of coal and each one of them when converted into mechanical energy is good for 778 foot pounds. It takes a good sized modern locomotive to weigh 200 tons. Imagine a string of 56,405 such locomotives. There is enough energy in your ton of coal to raise all of them with their drive wheels spinning in the air one foot above the rails. The trouble is that our methods of

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*A heat unit or one B. t. u. is the quantity of heat required to raise one pound of water one degree F. in temperature.

transforming and applying this energy are crude and inefficient. Old Mother Nature sat up nights for more than five million years to prepare this energy for us. Men toil and sometimes die in coal mines to get it for us. We buy it with the money that other men have toiled and sweated to produce. And after you get that ton of coal into your bunkers, how do you treat it? You arm an ignorant fireman with a 90-cent shovel and "sic" him on it. Now if I ask your fireman anything about excess air or the other causes of fuel loss within his powers of prevention he tries to rub his ears off with his shoulders. The shrug is his mode of expressing an absolute and ultimate negation of understanding. Is there anything about the bad effects of cold air on boiler surfaces that the fireman cannot understand? Somebody ought to explain the effects of air holes in the fire to him. He needs a little teaching. But nobody ever heard of anybody teaching any fireman anything in your boiler house. Your engineer knows that it is bad to allow cold air to flow in upon the tubes in the first pass of his water tube boilers, and yet I can shove a full grown tom cat through some of the holes around his boiler headers. Maybe you think I am lying about the air leaks. Go and see for yourself before you come to such conclusion. The trouble with the engineer is that he hasn't thought about these things. He just needs a jolt from somebody and I am trying to jolt him. The trouble with the Manager is that he believes the fuel economy question to be outside the purview of his jurisdiction. He leaves all such things to the superintendent or the engineer or somebody else below him. As Dr. Dowie used to express it, "He doesn't believe in keeping a dog and doing his own barking." The result is that nobody barks about fuel economy in your power plant and that is the reason for my barking and howling.

The spigot may be dripping in the engine room, but the bung is out in the boiler house.

CHAPTER III.

HOW TO "SPOT" YOUR FUEL WASTES.

Now that we know how the wastes occur and about where to look for them we will visit your boiler room and take a look at them. I have been harping on 25 per cent in the first two chapters as a measure of the preventable wastes in the boiler room. I don't know what your losses are because I was never in your boiler room. I do know that if the "hit or miss," "catch as catch can" methods prevailing in the average plant are to be found in yours, that your preventable furnace wastes, when we come to measure them, will be mighty close to a quarter of your coal.

Some twenty questions were propounded to the engineer in the first chapter, and he is entitled to know exactly how those questions may be answered. We will get ready to answer them.

WHAT IS THE EFFICIENCY OF YOUR BOILER FURNACES?

I put that question last summer to the manager of a big Southern factory. "Wait a moment," said he, "and I will tell you." He pushed a button, wrote a message on a slip of paper and sent it out by the office boy. In a few moments the paper was returned and this statement had been endorsed upon it by the chief engineer: "We produce a kilowatt with 5.341 pounds of coal." The Manager smiled in a satisfied way as he handed me the paper. "There's the answer to your question," said he, "worked out to three decimal places."

I replied, "Your answer is not responsive to my question." Every time I ask an engineer about the efficiency of his furnaces he begins to talk about the cost per kilowatt hour. Sometimes he has information on the pounds of water evaporated per pound of coal burned, which is closer to the point but still a long way from it. In either case he is

giving me the two ends of the process only, and leaving me entirely in the dark as to what is taking place between the extremes. Now I have nothing against your kilowatts and what-nots. It is of considerable importance that you should know the cost per kilowatt hour as it gives you a line on the over-all efficiency of your plant. But that is all it does do. Is there anything about that figure of 5.341 pounds of coal per kilowatt hour that will enable you to place your finger on any specific thing about your power plant and to say as you do so, 'We are wasting fuel here; we must do this and that and after we have done it we will have reduced the coal consumption per kilowatt hour?' Your engineer's bookkeeping is good as far as it goes, but it does not go far enough. It analyzes nothing for us and hence it gets us nowhere.

Now if you will take up the different factors in your power plant, one at a time, and scrutinize each of them without relation to any other you will get some information that means something. If you will bring each factor up to the highest possible state of efficiency you won't need to worry about the cost per kilowatt hour. It will take care of itself. It will be as low as it is possible to get it and you will have to be satisfied with it, whatever it is. No amount of bookkeeping will change it. If I should ask you about the efficiency of your stenographer would it be a responsive answer to tell me what your gross annual sales were last year? Or if I should ask you how you are feeling this morning, would it be a responsive answer to say that your family, consisting of your wife, your three children, your mother-in-law, the hired girl and yourself, were 50 per cent well? Now, when I try to find out how much coal you are wasting at the boiler furnace you give me a figure, that, if I knew the heat value of your coal, would tell me something about the combined efficiency of the fireman, the furnace, the boiler, the economizer, the superheater, the engine, the generator and the lubricating oil. We can't convict anything on the cost per kilowatt hour. The figure may tell us that something is wrong somewhere, but that is all it does tell us. It is of no fuel-saving, money-making use to us."

Much of the bookkeeping in power plants is useless be-

cause it leads to no useful end. In what way does it help you to know the cost per kilowatt hour if the information does not assist you to reduce the cost per kilowatt hour? You can get your cost of power by adding up each month all of the expenses that the power house has incurred and including a charge for interest and depreciation. Such general information will enable the manufacturer to determine the power cost per unit quantity of his product and this is necessary to his cost-keeping system. It is valuable also for purposes of comparison. Month can be compared with month and fiscal period with fiscal period. The unit fuel cost can also be compared with that of other factories in the same industry. While such comparison may result in satisfaction it is not likely to result in anything else. The fact that you are producing power at less cost per unit of product than your neighbor does not prove that you are producing it economically. There are degrees of waste. If the other fellow is wasting 40 per cent that is no reason why you should be complacent with a waste of 20 per cent.

I am not the first man to criticise the current system of power house bookkeeping. The following is quoted from one of the most prominent efficiency engineers in the United States:

"Consequently, the common practice is to compare the data at two extreme ends of process. Let us take, for instance, the number of pounds of coal at one end and the number of kilowatt hours generated at the other. With no knowledge of the heating value of coal used, nor the number of B. t. u. consumed per kilowatt hour, nor even of the mechanical efficiency of the equipment, we shall not be any the wiser as to the stage of the whole process in which the loss occurs, nor how big it is. We ought to know precisely how much is lost in certain steps of the transformation of energy from one form into another."

We cannot help saying "Amen" to that quotation.

The engineer will get some ideas on sensible power cost bookkeeping if he will study the nurse's daily chart the next time he is laid up in the hospital. The nurse is careful to record every fact relating to the patient's condition in which the doctor is interested. She brushes the patient's teeth and trims his toe nails, but she does not encumber the chart with these inconsequential details. She writes down only what the doctor wants to know and when the physician arrives he looks at the chart before he looks at the patient.

There are engineers who make a careful record of every-

thing without regard to what is important and what is not. Such bookkeeping is laborious, "costive" and to a large extent useless. There are other engineers who never make a record of anything. The sensible practice as to bookkeeping lies between these two extremes.

RECORDS OF MAINTENANCE

Date ____________________

BOILER	TUBES BLOWN				MUD BLOWN	CUT OUT	CUT IN	WASHED	SCALE REMOVED
1									
2									
3									
4									

	COMBUSTION CHAMBER CLEANED	CONDITION OF BAFFLING	COND. OF BRICK WORK	COND. OF BLOW OFF
1				
2				
3				
4				

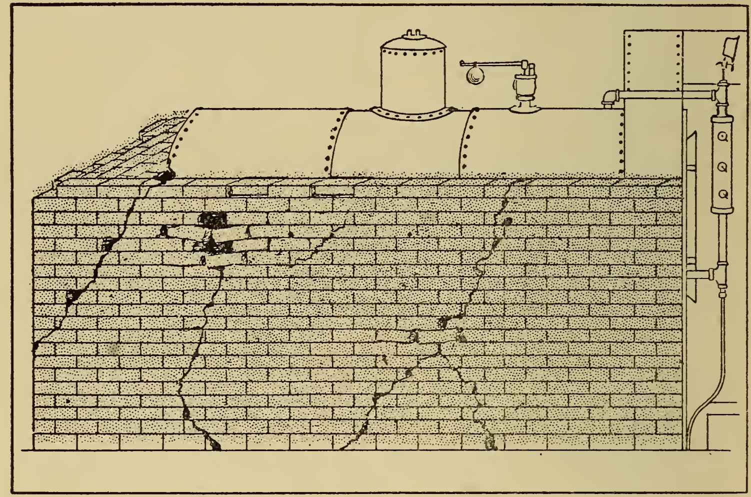
REPAIRS NEEDED ____________________

BOILER SUPT

I shall not attempt to outline any system of powerhouse bookkeeping. The records that you do employ, to be of use, must be to the point and reach the spot. Whatever else they may show, they should indicate the causes of waste and measure the effects. They should keep the physical condition of the boiler plant constantly before the Engineer and Manager. There should be records of maintenance as well as records of operation. If you will make some one man personally responsible for the physical condition of your furnaces and boilers and require signed reports on blanks furnished, you will not be bothered with soot and scale, with broken down baffles or with leaks in the brick work of the boiler settings.

Where nobody reports to anybody about anything and nobody is made responsible for anything, nothing need be expected because nobody is interested.

The illustration on this page is not an exaggeration. The boiler is not covered and the setting is disintegrating. You can actually find boilers and settings in that condition. The boilers in your plant are covered, of course, but there are leaks in the settings, as serious in the aggregate, perhaps, as those shown in the picture. I visited a large power plant in Brooklyn and the brick work of the boilers was in worse



shape than the horrible example at which you are now looking. They were "expecting to re-set the boilers" at some time in the indefinite future and hence they did not consider it worth while to do anything to "those old settings." A few dollars' worth of material and a few more dollars' worth of time would have calked the settings of the ten boilers and the firm would have made about 100 per cent a day on the investment.

It is much the same old story wherever you may go visiting power plants. Conditions exist in the boiler room that would not be permitted in any other department of the factory. Hence that waste of a quarter of the fuel.

By what criterion shall the efficiency of a furnace be judged?

THAT FURNACE IS THE MOST EFFICIENT WHICH COMPLETELY CONSUMES THE COMBUSTIBLE WITH THE LEAST SURPLUS OF AIR.

Here we have the whole thing in a very small nut-shell. No matter where we start or in which direction we proceed, whether we consider the subject of drafts, of fuels, of methods of firing or what not, it is just a question of complete combustion with the minimum of air. Fix this in your mind and much of the "mystery" will fall away from the combustion problems that have been troubling you.

Flue gas analysis answers every question bearing upon the efficiency of the *furnace proper,* but it tells us absolutely nothing about *boiler* efficiency. No other form of furnace test ever has been or ever will be devised to supersede it. The furnace exists solely for the gases that are delivered from it, as it is from these heat laden gases that the boiler derives the energy necessary to its functions. Every judgment upon furnace efficiency must therefore be based upon an inquiry into the furnace gases. I can prove it by scripture. The gases are the fruits of the furnace and "By their fruits ye shall know them."

When it is suggested that a test should be run upon the boiler furnace the engineer by force of habit begins to think of the standard evaporation test because it is the only test with which most engineers are familiar. There can be no quarrel with this test if it is a complete one and properly conducted. It is incomplete unless sufficient combustion facts are gathered to enable us to judge the furnace as a thing quite apart from the boiler. The boiler has nothing to do with combustion and the furnace has nothing to do with evaporation. You do not burn coal in the boiler nor evaporate water in the furnace. Hence when we are considering furnace efficiency alone, no question as to water evaporated should enter the problem and add its complications.

The business of the furnace is to transform the heat energy contained in the coal—to change it from the latent to the active condition and to deliver it in such condition undiluted and unmodified to the boiler.

The business of the boiler is to take the heat energy from the carrier gases and make steam with it. We may have a very efficient furnace delivering heat energy to a very inefficient boiler. The furnace is not to blame for the character or physical condition of the boiler. The only exception that must be made to this statement relates to soot deposits and in many cases these deposits are the fault of the boiler and not of the furnace.

There was a time when furnaces and stokers were sold under specified guaranties of evaporation. The wonder is that manufacturers ever stood for such an unfair method of judging their products. The leading furnace and stoker people are getting away from it and refusing to assume responsibility for the boilers that they do not furnish. They are guaranteeing furnace performance without reference to evaporation and the efficiency of the furnace is determined by an examination of the gases that it passes along to the boiler. This is the only fair method and the only scientific one.

You do not try on your coat to determine whether your pants fit, and if the pants are too short in the legs you do not remedy the trouble by cutting off your coat tails. Pants are a part of a suit of clothes, just as a furnace is a part of a steam generating plant and as the study we are about to make relates primarily to the furnace we will leave the boiler out of it as far as it is possible to do so. The subject of boiler scale is of such compelling importance that I have been tempted to deal with it here in connection with furnace problems. I am precluded by lack of space from doing so. We will stick to the furnace proper as far as possible. We are forced, however, to consider the subject of air dilution at all points between the furnace and the chimney and we must also take the question of the "short-circuiting" of the gases into account. It is quite impossible to make a proper combustion study without considering the physical state of the walls that enclose the boiler and of the baffles that direct the flow of the gases through the boiler. For the purposes of this study we will consider the boiler damper and everything except the naked boiler itself as a part of the furnace.

The efficiency of the furnace depends upon the efficiency

of combustion within the furnace and the safeguarding of the gases from outside influences until they have left the heating surfaces of the boiler. Now it is quite impossible for any one to look at a boiler and furnace and pronounce a definite judgment upon the efficiency of either of them. We can tell in a general way whether combustion is efficient or inefficient by observing the color of the flame and noting the condition of the fuel in the furnace, but the judgment of the observer might be 10 or 20 per cent at fault. The fuel itself has much to do with appearances in the furnace. What applies to one fuel and one furnace will not apply at all to another. And even if it were possible to look at a furnace and say, "This furnace is doing absolutely all that can be expected of it," it would be quite impossible to say that the boiler was having a fair chance at the hot gases delivered by the furnace.

There are four large water tube boilers in the sub-basement of a well-known New York office building. Three of these boilers were good steamers. The fourth was a shirker. Its furnace received as much attention as the others. The boiler walls and baffling were carefully looked after. The tubes were known to be clean of soot and scale. But the boiler just balked and wouldn't steam, and what ailed it was a problem. The gases leaving that boiler were finally examined with a Flue Gas Analyzer and it was found that they carried a high percentage of excess air. It was a mystery where this excess was getting access to the boiler. The engineer was willing to swear that there were no air leaks anywhere about the boiler and the analyzer declared there was a big air leak somewhere. The boiler was shut down and the engineer crawled into the combustion chamber where he found the trouble. It had been the practice at one time to sluice the ashes through a 12-inch conduit which extended from the ash pit back under the combustion chamber to the rear of the boiler. Another method of ash handling had been adopted and the conduit was forgotten. It had been broken through by some laborer when cleaning out the combustion chamber and the result was an air leak into the combustion chamber 12 inches in diameter.

Many stories having a similar bearing upon the subject

could be related. If there is more than 40 per cent excess air in the gases as they leave the heating surfaces of the boiler, something is wrong somewhere. An exception must be entered to this rule if the coal contains an abnormal percentage of ash or if the ash has a disposition to fuse at low temperature. In such circumstances it is impossible to burn the coal effectively with as little as 40 per cent air excess. It has been estimated that when the coal carries 40 per cent ash the efficiency of the heat unit is zero.

Let us now tackle one of your boilers and make an exact diagnosis of the combustion troubles which afflict efficiency. We shall require the following apparatus:

1. Some tallow candles.
2. A flue gas analyzer.
3. A sensitive differential draft gage.
4. A high temperature thermometer or pyrometer.

We will begin our study with the analyzer and we shall need a piece of one-eighth or one-quarter-inch gas pipe long enough to reach the center of the gas "flow" at the point where the gases leave the heating surfaces of the boiler.

In another chapter I have discussed Gas Analyzers and other forms of testing apparatus, explaining the principles upon which they depend and the methods of operation. As to the requisites of an Analyzer for making a study of furnace conditions I will merely say here that speed is absolutely essential. The conditions in the furnace may change from instant to instant and when a sample of gas is taken for analysis, all of the conditions obtaining when the sample is drawn must be observed and a record made of them, otherwise we shall be unable to interpret the real meaning of any analysis we may make. For example, we want to know the effect that the slightest change in the draft will have upon the volume of excess air flowing through the furnace. We wish to make five or six tests as close together as possible, varying the draft for each test. Now the excess of air will be affected by changes in the condition of the fuel on the grates as well as by changes of the draft. As the fuel burns down the resistance to the passage of the air will be less and a small fissure may form in the fuel bed at any moment,

letting in quite a volume of air. This would of course affect the result and we would have no means of knowing whether the change in the volume of excess air indicated by the Analyzer was due to the change in the draft or the change in the conditions in the furnace. Hence speed in operating the Gas Analyzer is a requisite of the highest importance when we are diagnosing furnace conditions. Failure to appreciate this fact has led to many wrong conclusions by engineers and some of them have formed quite erroneous impressions of the value of flue gas analysis on account of it.

The gas sample should be taken from the point where the gases leave the heating surfaces of the boiler. It should be taken from the center of the gas flow at that point and it should be taken through a length of ordinary one-eighth or one-quarter inch iron gas pipe. Under no circumstances use a perforated pipe. If you take the gas sample at any other place or in any other way, you will not get the information you are after. I must make the reasons for these suggestions as clear as possible, because it is by disregarding them that the beginner with the Gas Analyzer makes his first mistakes.

The sample should be taken at the point where the gases leave the heating surfaces of the boiler because you wish to catch all of the air leakage that is really affecting efficiency. Any outside air that may find its way into the boiler passes between that point and the furnace will reduce efficiency. If your gas sample is taken from the first pass of the boiler you will miss all of the air that is flowing into the second and third passes. The reading of the analyzer would tell you the extent of air dilution in the first pass, but nothing about the final condition of the gases, and it is the final condition that you are after. For the same reasons it would be the very worst of bad practice to take the gas sample from the breeching or any other point beyond the heating surfaces of the boiler. It is quite certain that there are air leaks around the breeching connection and quite likely through the seams of the breeching itself. If the sample is taken from the first pass the analysis may indicate much less damaging excess than really exists and if taken from the breeching it is almost sure to indicate a great deal more.

The temperature of the escaping flue gases should be taken at the same point where the gas sample is obtained and for the same reasons. You want to know how hot the gases are when they leave the boiler, not how hot they may be after they have chilled down by radiation and air leakage beyond the boiler.

Air leakage into the breeching will not lower the efficiency of the boiler in ordinary circumstances. Under certain conditions it might improve efficiency by cutting down the draft as the tendency in most boiler plants is to use too much draft.

I visited a power plant not long ago and found an evaporation test in progress. Gas samples were being drawn regularly into a bottle at one hour intervals and carried to the laboratory where they were carefully analyzed by the plant chemist. He was very careful to determine the exact percentages of CO_2 (Carbon Dioxide), O_2 (Oxygen) and CO (Carbon Monoxide). The boys were going to work out a heat balance at the conclusion of the test and to this end they were very anxious that the gas analyses should be made just right. The weights of coal burned from hour to hour and the reports of the water and steam flow meters indicated a very high efficiency, while the chemist's reports on the gas samples indicated a low efficiency—a very large volume of excess air. They couldn't understand it. The man in charge of the test had forgotten more about electrical engineering than I will ever know, but he didn't know the "A. B. C." of practical flue gas analysis. "What do you think of that 6 per cent CO_2?" he asked me. I was forced to tell him that it was "rotten" and that he ought to be getting about 14 per cent. "I will give you five dollars," he said, "if you will show me how to make that Roney stoker do any better than it is doing right now." We looked at the fires and they were dazzling white. We looked at them through smoked glasses and there was no sign of an air leak in the fuel bed anywhere. "I can't show you how to work a Roney stoker," I said, "but I can show you something about analyzing flue gases. From what point are you taking the gas samples?" "Why," said he, "from the uptake of the boiler, of course, from what point would you take them?"

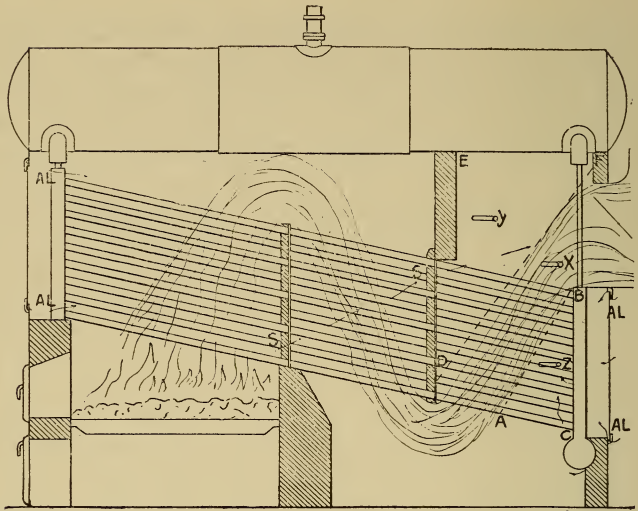
We got a ladder and climbed to the top of the boiler. The gas samples were being drawn from the uptake, above the boiler damper and about 12 feet above the drums of the boiler. There was more air going in around the hood of that breeching than was being taken through the fuel on the grates of the stoker. The gas samples over which his chemist was working with such great care to insure exact determinations were utterly worthless. We then took a gas sample from the last pass of the boiler and the very first reading showed more than 15 per cent CO_2, indicating an air excess in the last pass of less than 40 per cent, while the samples taken from the uptake were showing an air excess of nearly 250 per cent.

One gas sample per hour is very little better than no gas sample at all. It is not enough to indicate an average. To indicate anything approaching the real average the samples should be taken as often as once every five minutes and it would be better to have a continuous sample. The conditions in the furnace affecting the flue gases are not constant, even with the best types of stokers.

Don't forget this: The gas sample must be taken at the point where the gases leave the heating surfaces of the boiler, wherever that point may be. Where that point may be located and how you are going to reach it with a piece of gas pipe, will depend upon the type of your boiler.

Remember the boiler damper when you are placing the Sampling tube. The gas currents may be deflected by the damper and leave the Sampling tube in a dead air space.

Incorrect Positions of the Sampling Tube.



"X" shows the correct location for gas sampling pipe—"Y" and "Z" the incorrect locations. The points marked "AL" show some of the places where air leakage is likely to be found. If the "baffling" is in bad condition the gases may "short-circuit" as shown by the arrows "S" "S."

The tube must be in the gas currents, whatever the position of the damper.

If it is a boiler of the "B. & W." type you can thrust the gas pipe through the top "blow hole" at the last pass and let the pipe rest upon the boiler tubes. If it is of the "Heine" type you can run the gas pipe through one of the hollow stay bolt holes. If it is a return tubular boiler you can remove the top "handle" from one of the boiler doors. This will provide a hole through which the gas pipe may be passed, and you must be sure that you are not getting any of the air that leaks around the boiler doors into the smoke box. The gases will leave the boiler tubes and rise in a curve to the uptake. Between these curving gas currents and the boiler doors there will be a current of air on its way to the uptake and the volume of the air stream will depend upon the amount of the air leakage around the boiler doors. Your gas pipe must pass through this stream of air and its open end must be in the gas currents. In ordinary circumstances the pipe should extend to within about six inches of the boiler head and it should be above the top row of

tubes. If the pipe should be thrust in too far it might extend beyond the curving flow of the gas currents and enter a "dead air" space. Be certain that you are getting none of that air leakage around the boiler doors. If you are not certain, stop the leaks temporarily and if this is impractical insert the gas pipe in one of the boiler tubes as the next best expedient. This will give you gas from but one of the boiler tubes and you want a composite sample from as many of the tubes as possible. I have found by experiment, however, that an analysis of the gas taken from one tube will compare very closely with that of a sample taken in the preferred way as above indicated, provided the tube selected is near the center of the boiler. If there is much air leakage between the arch at the rear of the boiler and the boiler head, a sample taken from one of the top row of tubes might show more air excess than a sample taken lower down, as most of the air flowing in at the arch would find its way into the top row of tubes.

Many years ago somebody suggested the use of a perforated metal pipe for gas sampling purposes. It was proposed that a gas pipe long enough to extend entirely across the boiler should be used, that this pipe should be capped or plugged at the end and perforated with small holes at measured intervals—the theory being that when suction was applied to the pipe each of the holes would furnish its quota of gas and that the sample secured would represent an average of the gases flowing through the cross section of the boiler pass in which the pipe was extended. The use of such a pipe is to be condemned for the following reasons:

1st. Gas will flow along the lines of least resistance. The nearest hole will furnish more gas than the next one and so on down the line. Unless the suction applied is very strong the chances are that the bulk of the gas, if not all of it, will be drawn through the first hole. If the rate of gas suction is very slow, as for example, when a gas collecting device is used, one lone hole in the perforated pipe would be more than ample to supply all of the gas taken.

2nd. Some of the small holes in the perforated pipe are quite certain to be stopped with soot accumulations and one would have no means of knowing when such stoppage had occurred nor which holes had been affected.

3rd. The velocity of the gas flow decreases from the center of the boiler pass toward the sides, so that even if it were possible to secure uniformity of gas flow through all of the perforations in the tube, the sample derived would not be an average one. Assuming such uniformity of flow, the hole drawing from the slow moving gas current would supply as much gas as the one drawing from the fast moving gases. This would make the "average" secured a false one and as the gases near the sides of the boiler carry more of an air excess than those at the center, the sample would be rendered falser still.

4th. There is no sense in taking a cross sectional sample from side to side of the boiler pass unless you add to this sample another cross-sectional one extending longitudinally with the boiler from baffle to baffle. If there is any merit at all in the perforated pipe there should be at least one opening for every square foot of space throughout a horizontal cross-section of the entire pass of the boiler.

It is quite impossible to secure an absolutely correct average sample of gas through any pipe or any nest of pipes that could be devised. It is my opinion, and I base it upon a great deal of experimenting, that a better sample can be secured through an ordinary gas pipe opening at the center of the gas flow, than in any other manner. The gases are reasonably well mixed when they arrive at the exit of the last pass. They have been tumbled up and down among the boiler tubes, and the point of best mixture is the point of greatest velocity, viz., at the center of the gas flow. You will find greater variations in the CO_2 content of the gases at the center of the flow than at any other part of the pass. If taking samples at that point you can tell from the analysis when the furnace doors are opened for stoking, when an air hole develops in the fuel bed and what the exact effect of the slightest change in the draft may be. Everything that happens to affect efficiency is reported by the gases having the greatest velocity, i. e., the gases at the center of the flow and as you move away from the center towards the sides of the pass or towards the baffles, the variations will be less and less pronounced and when you reach a point very near the side walls there will be practically no variations at all.

About two years ago I received a letter from the Chief Engineer of a cotton mill. He stated that he was using a perforated sampling pipe and that he was unable to get more than 2 per cent CO_2. I told him to throw the perforated thing away and to go for the center of the last pass with a piece of common pipe. He did so and reported 13 per cent CO_2. The first hole in his perforated pipe had furnished all of the gas and the gas that it furnished was principally air that had seeped through the brick work of the setting.

Flue gas analysis as a means of determining furnace efficiency has been condemned by a great many well meaning engineers. They have taken the gas sample from the uptake or some other place, not the right one. They have used a perforated tube or they have done something else not in accord with good practice. They have not secured results and hence they condemn the whole proposition. I have yet to learn of a single instance where satisfactory results in the actual reduction of fuel bills were not secured when the right methods were followed.

Having learned what sort of a sampling pipe to use and where to place it, the next step is to connect the Gas Analyzer by means of its flexible rubber hose with the sampling pipe. Drive a nail into the brick work of the boiler setting or wherever you wish to hang the Analyzer and see that the Instrument is at a proper height to facilitate ease in operation. Don't stand it inconveniently on a box or a barrel. You must work rapidly when you get started, because you are out after useful data. You must make 50 or more CO_2 determinations per hour and at the end of an hour you ought to have the goods on the furnace and the fireman.

Your next step is to connect the differential draft gage, and I must digress here to say something about drafts and draft measurements.

Owners and engineers of power plants are frequently heard complaining about the "draft" and saying all manner of unkind things about the chimney. Most steam plants suffer from too much draft rather than from too little of it. If you have draft troubles look for the causes of them in the boiler room before you blame the chimney. What you label "lack of stack capacity" may, perhaps, be more properly

labeled "lack of engineering sagacity." You probably have chimney enough and draft enough. What you need is draft conservation.

By way of making clear what I am trying to convey let me present an illustration. Let us suppose a farmer who wishes to take a load of grain to market. He has been out in the field with a wagon picking up "nigger heads" and other stony impediments to cultivation. He gathers just about all that the horses can draw but the load does not fill the wagon box. He wants to take some grain to market. Being a lazy individual and being in a hurry to get to town and cash in on his grain, he does not unload the "nigger heads." He piles the grain in on top of them and of course he gets stuck in a sand pocket going up Sugar Creek hill. I submit that it would not be fair in such a case to blame the horses. The Society for the Prevention of Cruelty to Animals should get after the farmer and a commission to determine lunacy should sit on him. Undoubtedly both of these things would happen.

Good engineering is just good horse sense. When the capacity of either a horse or a chimney to do useful work is reduced by the performance of useless work, somebody is not exercising horse sense.

I have investigated a great many cases where "poor draft" was alleged and in most instances I have found the chimney pulling about five tons of "nigger head" ballast for every ton of real cargo. And in nearly every case it has been possible to greatly increase the effective draft by throwing out the ballast. In some cases it has been necessary to make certain alterations in the flue connections, but in very few cases has it been necessary to do anything to the chimney proper beyond ordinary repairs.

We are told that it requires eleven and a half pounds of air to burn a pound of "coal," or around 23,000 pounds for each short ton of coal. The draft must raise this weight to the top of the chimney and in addition it must raise the combustible portions of your coal, for the oxygen of the air unites with the carbon of the coal to form the gas CO_2, and the hydrogen of the coal unites with oxygen to form water vapor, H_2O. The total weight that the draft *must* raise

in the performance of useful work is therefore around 25,000 pounds for each ton of coal consumed, or 2,500,000 foot pounds if your chimney is 100 feet high.

Now suppose that the flue gases show 5 per cent CO_2, which in all probability is about what they do show. This means that added to the weight of 25,000 pounds which the chimney must lift there is an excess ballast of "nigger heads" weighing right at 72,220 pounds to be lifted also. The chimney under such circumstances would be doing enough work to carry three plants like yours at full capacity and with maximum economy. And yet the owner of such an overworked and uselessly worked chimney is persuaded that there is something wrong with it. He spends a lot of money for more boilers and chimneys with the result that his fuel bills go up instead of down, because he has to buy still more coal to heat still more air.

The only thing that draft knows is to burn fuel and if you have too much draft after the new chimney has been built or after you have thrown out the ballast and given the old one a chance, you must throttle this draft as you throttle the steam at the engine. Your throttle is the boiler damper.

Excess draft increases your fuel wastes in several ways. It increases the rate at which you burn the coal without a commensurate increase in the rate of evaporation. The heat of some of the extra coal that you burn is nullified by some of the excess air that is drawn in by the excess draft. The velocity of the gases is probably increased and in such case the boiler has less time in which to absorb the heat energy. The stack temperatures are higher. You lose at both ends and the middle.

A proper draft gage is an important boiler room appliance. It measures the actual draft used, but it cannot tell you the draft that you ought to use. It is like the scales that the druggist employs. These tell him the weights of the drugs he is measuring out, but they do not write prescriptions. The Gas Analyzer prescribes the draft that should be employed. The draft that will give you complete combustion and carry your load with the least excess of air is the draft to be used always. The Gas Analyzer

measures the completeness of combustion and the excess of air.

Engineers persist in connecting their draft gages at the up-takes of their boiler furnaces. In this case, as in many others, the common practice is the wrong practice. Suppose you wish to know the water pressure in the supply pipes of your residence. Where do you measure that pressure? Do you measure it at the pumping station of the water company where it originates or do you measure it at the faucet in your kitchen, where the effective pressure is expressed? The rate at which you burn your fuel in the furnace depends upon the rate at which you apply air to it, and this rate, so far as a draft gage can measure it, is fixed by the draft in the furnace. The place to measure drafts, accordingly, is the boiler furnace where the draft is applied. Of course, if you burn your coal in the uptake of the boiler instead of in the furnace, it is another matter, and you may leave your draft gage, if you have one, connected at the uptake where it now is.

The draft gage, it must be remembered, does not measure gas flow or gas velocities. It merely measures differences in pressure,—the pressure of the atmosphere on the outside and the something less than atmospheric pressure on the inside of the furnace. Under normal conditions, viz., when the fires are clean and of known and uniform thickness, when the furnace doors are closed and the ash-pit doors open, the draft gage may tell us something about gas velocities,—the greater the draft the greater the velocity. Now suppose we close the ash-pit doors,—what happens? The draft, as indicated by the gage will be increased, but the movement of the gases will be decreased because we have shut off the supply of air. If the air is entirely excluded there will be no movement at all and hence no velocity whatever. On the other hand, if we open the furnace door air will rush in and move with considerable velocity through the furnace and the boiler. But the gage will show that there is less draft,—less difference in pressure than before the doors were opened. Velocity may be either directly or indirectly proportional to the draft as indicated by a differential pressure gage.

What causes chimney draft? The force that is trying to go up the stack is stronger than the force that is trying to come down the stack. Hence there is a movement up the stack and draft is a "push" and not a "pull" as is commonly supposed and as its name implies.

Suppose, by way of illustrating the physical cause of draft, that we take a glass tube and insert it in a bottle of oil. By closing the tube with the finger we can lift out a tube full of oil. Let us next insert the oil filled tube in a vessel of water and remove the finger. Water will flow in at the bottom of the tube and push out the oil. The water, in seeking its level, exerts an upward pressure in the bottom of the tube that is greater than the downward pressure of the oil. Oil being lighter than water will rise to the surface of the water.

Let us suppose again that the oil filled tube is 6 inches long and that we push it down in the water before removing the finger until the lower end of the tube is 3 feet under water. We shall then have a downward pressure at the bottom of the tube of 2 feet 6 inches of water plus 6 inches of oil, and an upward pressure of 3 feet of water. This would make the net upward pressure at the bottom of the tube exactly equal the difference between the weight of the oil in the tube and that of a corresponding 6 inch tube-full of water.

Oil is lighter than water. Hot gas is lighter than cold gas. Air is a mixture of gases. Your hundred foot chimney full of hot gas stands at the bottom of a sea of air some 50 miles deep. Precisely as in the case of the water and the oil, the net upward pressure at the bottom of the chimney exactly equals the difference between the weight of the column of hot light gas in the chimney and that of a like column of cold heavy air outside the chimney. And as the barometric pressure varies your draft will vary also. It is strange how many people there are who do not clearly understand these simple draft phenomena. If everybody understood them there would be far less money spent for new chimneys and far less kicking about drafts.

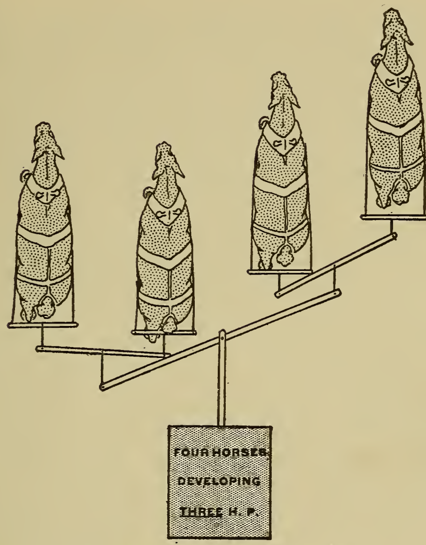
"Nature abhors a vacuum" and tries her best to destroy one. There is a partial vacuum inside your boiler furnace

and all the way from the furnace to the top of the stack. Nature tries to destroy that vacuum and incidently to destroy your draft by shoving cold air into it, through the fuel bed in the furnace, through crevices and cracks about the furnace, through cracks in the brick work of the setting, through the pores of the bricks themselves, through air holes around the headers at both ends of the boiler, through leaks in the flue connections and breeching and through cracks and leaks in the chimney. The way to fix nature is to fix these air leaks.

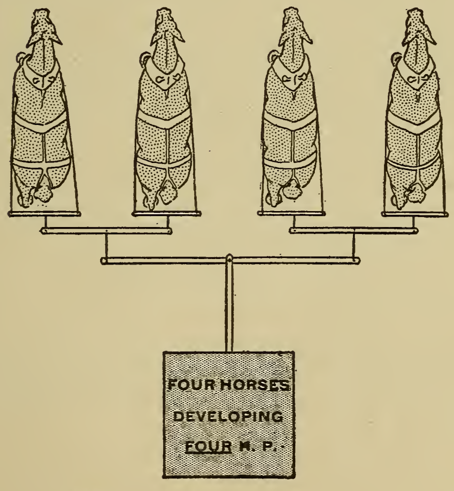
A steel chimney will radiate more heat than a brick or tile one and loss of heat means loss of draft. When putting up a chimney it will pay you to put up a little more money and get a real one. In the ideal chimney the temperature at the top of the stack will closely approximate that at the bottom. The steel chimney is a radiator and it takes the heat out of the gases as they travel through it, thereby impairing the draft to the extent of the heat robbery.

If you will do the square thing by your chimney and give it a show,—forcing it to perform useful work only—you will find that most of your draft trouble has disappeared and that the large expense you have been dreading incident to a new chimney or a higher one may be avoided.

And having decided to give your chimney a fair show why not stop playing favorites with your boiler? Why do you have so much affection for the boiler nearest the stack and so little for the one farthest from it? Don't you know that some of your boilers get more than their share of the draft provided by the chimney and that others get less than their share of it? This isn't fair, either to yourself or to your boilers. It costs fuel and adds to your troubles with the smoke inspector. It gives you as many combustion problems as you have boilers and furnace drafts. Why, a farmer's boy knows enough to make his plow horses pull together. Drive your boilers the way the boy drives his horses. First find out what draft you ought to use in your boiler furnaces. This draft, as I have stated, is the one that will produce the highest percentage of CO_2 without combustible CO and carry your load. You have a draft gage for each boiler or ought to have. They are not expensive. After



No two of them pulling alike. That's no way to work the horses' It's just the way you work your boilers.



Make your horses pull together. Work your boilers in the same manner.

learning the draft that you ought to use, you can equalize the draft by setting the individual boiler dampers. I have known eight boilers to do the work that ten were doing before, after draft equalization. If a furnace has too much draft there will be a fuel loss due to heating excess air. If it has too little draft there will be a fuel loss on account of the CO which is due to a deficiency of air.

Draft gages are of great assistance to the fireman. They enable him to give each boiler furnace the exact draft that it should have—the standard draft for the plant, whatever that draft may be. They enable him to spot the fire that is getting in bad condition. The gage will show an increased draft when the fires are too thick or are becoming dirty. It will show a decreased draft when the fires are too thin or when they are burning full of cracks and holes. The gage when properly connected will show the draft loss between the uptake and the boiler furnace. If the loss is less than normal, you will know that something has happened to reduce the friction in the boiler passes, that the baffling has burned out or has broken down and that the gases are short-circuiting. If the draft loss is more than normal you will know that something has happened to increase friction, that there are deposits of soot and ash upon the tubes and perhaps slag, soot and ash accumulations upon the baffles and the brick work of the setting. These deposits upon the tubes affect both the efficiency and capacity of the boiler by resisting the passage of heat energy from the gases to the water in the boiler. They make the chimney work harder to give the required draft to the furnace. And they will be found among the chickens that come home to roost once a month upon the coal bill.

Some men are willing to spend a lot to save a little, but stick when it comes to spending a a little to save a lot.

CHAPTER IV.

HOW TO STOP YOUR FUEL WASTES.

It is one thing to "spot" a waste and another to stop it. The apparatus for spotting was mentioned in the last Chapter. For stopping the losses you require what is known as "Spizzerinktum." This is a state of mind—a mental self-starting device that enables you to get going without waiting for somebody to come along and crank up your motor.

Give the man who is loaded with "Spizzerinktum" a good steer and that is all he requires. He will square his shoulders, tuck in his shirt-tail and go to it. But the man who is not loaded with it—his case is hopeless. You might give him a whole herd of steers and other long-horned cattle and it wouldn't help him. You might kick him in the gluteus maximus every five minutes and it wouldn't hurry him. It takes that sort of chap about ten hours by the stop watch to pass a given point on any proposition.

Show me an engineer who lacks "Spizzerinktum" and I will show you a plant so low down in the scale of efficiency that you will have to look up when you visit it to see bottom.

Not long ago a plant Manager said to me, "We have bought every imaginable kind of testing and recording apparatus for our power department and none of it is used regularly. I believe that considerable might be accomplished if our engineer would take some interest and get busy. He is always just going to turn things upside down, but he never gets started." There is only one thing to do with that kind of a man. Tie a can to him and send him down south of the Rio Grande into the "manana country" to herd with the Greasers.

Men who are accustomed to visiting power plants will tell you that the reason most plants are so low in efficiency

is that the men in charge of them and the men back of the men in charge lack "Spizzerinktum."

We will now get busy with the "spotting" apparatus mentioned in the last chapter.

The manufacturer of whom you purchased your draft gages has surely provided you with explicit directions for connecting the gages with the boiler furnaces. If he has not done so he ought not to be in the business of making gages. We will assume that the gage is properly connected and that everything is ready. We will assume also that the boiler to be tested is one of the "B. & W." type.

You shove the gas pipe, selected in Chapter III, through the top blow hole of the last pass of the boiler and I ask you as you do so to note whether the pipe has the "feel" of contacting with clean metal or with something that is soft and dirty.

I was talking one time with the engineer of a very modern power plant in the very modern city of Minneapolis. We got around to soot and the engineer said, "I will show you that we keep our boiler tubes clean." He raised the slide over one of the blow holes at the first pass of the boiler. There was a good light from the furnace just below the tubes and we had a fair view of them. They were reasonably clean. We then went to the back pass of the boiler, but there was no light from the furnace there and we could not see anything. I asked for an electric flash light and the engineer said that he could steal one "off" the night watchman. While he was gone in search of it I found a piece of gas pipe about six feet long and thrust this through each of the blow holes of the last pass and across the tubes of the boiler. I could tell from the "feel" of the pipe that there was a surprise in store for my engineer friend. His flash light showed furrows an inch deep in soot where I had plowed with the gas pipe across the tops of the tubes.

Now it was evident that the man who had blown those tubes had not finished the job. He had blown the soot from the first pass back into the second and the double dose of soot from there back into the third. Then he had stopped to rest, or to look at a dog fight, or to visit the can or for some other purpose. At any rate he had not

finished his work. Now if things like that can happen in well regulated plants what can we expect to find in plants that are not regulated at all?

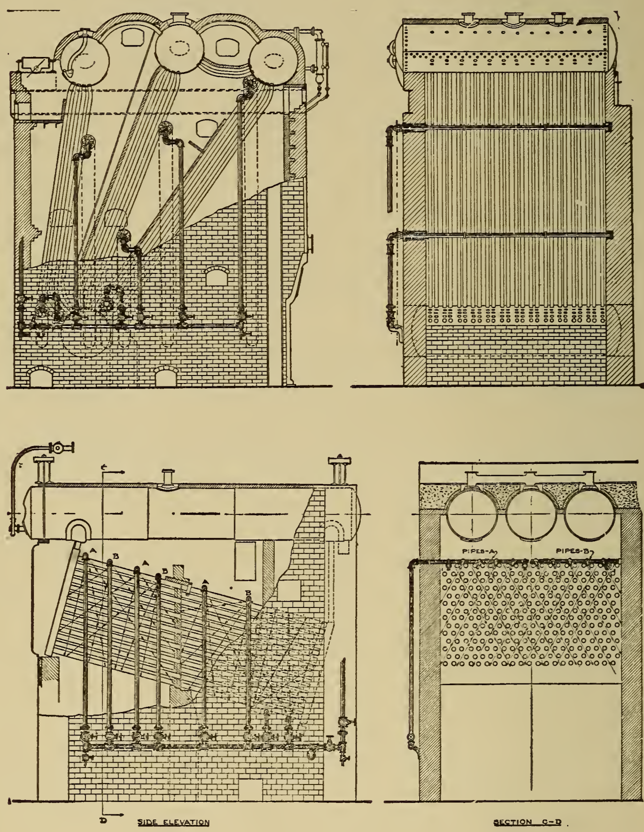
I have seen boiler tubes entirely covered with soot, so thick in places that the spaces between the tubes were actually bridged over. And the boiler room men really went through the motions from time to time of blowing the soot from the tubes. They didn't do the job properly at any time. Probably the nasty features of the work had something to do with the slovenliness of its performance. To clean off soot properly all of it should be blown off all of the tubes. To blow it from one locality to another doesn't help much. It is no uncommon thing to find soot so thickly packed into the corners and along the side walls of water tube boilers that you could use a hoe and shovel in removing it.

In non-conducting properties, soot has been proved to be five times as effective as fine asbestos. It is one of the most effective of all known non-conductors. You want your boiler tubes to conduct heat as rapidly as possible to the water within the tubes. If you want to keep up steam when the soot piles up you will have to pile in more coal.

And don't think for a moment that there is no occasion to use your soot blower because you make no smoke. If your furnaces never smoke at all there can be little, if any, soot upon the tubes, but there can be a great deal of fine ash, even from anthracite coal. Do you know how much fine ash was removed from the combustion chambers of your boilers the last time they were cleaned? There were wagon loads of it, most likely. Every bit of it was carried over from the furnace by the gases. And if that quantity of ash was carried through the tubes it is reasonable to presume that some of it landed on the tubes.

If you are fixed to blow the tubes economically by a permanent installation of blowers, don't be scared of blowing them too frequently. Two or three times a day will be none too often. Whenever you see smoke coming from your chimney, think of the deposit it is leaving upon the tubes. There is mighty little of real fuel value in black smoke, probably not to exceed 2 per cent of the fuel at the ex-

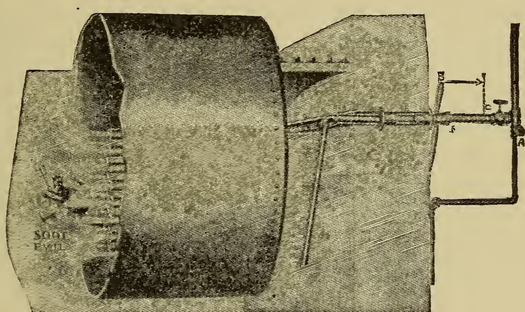
Showing permanent installations of Soot Blowers on Stirling and B. & W. Boilers



Soot is the long suit
in the winning hand
of the Waste Devil

treme figure in the extremest smoke. This has been proved many times by the use of soot traps and by analysis of the smoke. And yet the smoke may cause a loss of many times 2 per cent. The loss is not in the soot that goes up the chimney. It is in the soot that sticks to the tubes and does not go up the chimney.

And a bad thing about soot on the tubes is that if you do not get it off it is liable to bake there and if this happens very serious trouble may result. I recall one case



Scaring Old Mrs. Soot Evil off her nest. An arrangement for blowing soot from a Return Tubular Boiler

of a return tubular boiler that will serve as an example of carbonaceous scale. There was almost a quarter of an inch of it baked to the tubes. On reaming out one of the tubes a leak was developed and the boiler inspector condemned all of the tubes. The leak was due to the corrosive action of the sulphur baked on with the soot. When the tubes were removed the majority of them were found to be pitted.

Air leaks about boiler settings get on my nerves because there is no excuse whatever for them. You do not have to be told that they are bad for efficiency. Soot gets on my nerves for the same reason. If you want to see the soot on the boiler tubes stand up and show its bristles, poke around with a piece of gas pipe and peek around with a flash light.

Of course, if you want soot, why, suit yourself. And help yourself liberally to it. There is plenty of it.

Before you start work with the Gas Analyzer get a

piece of chalk and a foot rule and borrow the fireman's wide-bladed hoe. Chalk a scale in inches on the hoe blade. You can then set the hoe blade up on edge on the furnace grates and tell exactly how thick the fuel may be on the grates. Next have the engineer draw a sample of gas and determine the percentage of CO_2. While he is pumping the gas sample, read the draft gage and while he is analyzing the sample, look in the furnace and note the condition of the "fire," especially as regards the state of the fuel on the grates. Make a careful memorandum of whatever you see and note especially whether the coal is evenly distributed or all "hills and hollows." And look for cracks and thin places in the fuel bed. And don't forget to look in the corners at the front of the furnace. You may find bare spots there and you are almost sure to find one just back of the brick work between the furnace doors. It is a little difficult to get fuel on these places because it is hard to throw coal around a corner and the fireman is likely to slide over anything that is hard to do.

If it is a stoker instead of a hand-fired furnace you will make the same sort of observations to detect air leaks. Instead of looking for air leaks in the corners you will look in the hoppers and instead of looking through the furnace door you will look through the observation door. Everything that I am saying about hand-fired furnaces applies in one way or another to automatic stokers. The stoker has this advantage among others over a hand-fired furnace—you do not have to open the furnace door and let in a lot of cold air when you are putting in the coal. The hand-fired furnace has this advantage over the stoker. When the fire needs anything you can see what it needs and where it needs it and you can give it what it needs. If the boilers are set in battery, guess work must very largely prevail in looking after the stokers. The stoker requires attention the same as the hand-fired furnace and it requires a higher order of intelligence. Of course, there are stokers and stokers, but whatever type of stoker you may have you must not make the mistake of thinking that it will take care of itself. One of the most efficient plants I ever saw was hand fired and one of the most wasteful was stoker fired.

If you will permit me to pick the stoker and the stoker attendant I will back the machine against hand firing.

Furnace efficiency depends upon little things and many of them. One little thing may not mean much, but many of them mean a waste of one quarter of your fuel. There is no place to draw the line on these little things. You must observe all of them.

Now, if when inspecting conditions in the furnace, you find that the coal is evenly distributed, set up the hoe that you have calibrated and determine the thickness of the fuel bed. Do this from time to time as the test proceeds. If the coal is not evenly distributed, you cannot, of course, measure the fuel thickness.

While you have been inspecting the furnace the engineer has been analyzing and he now reports, let us say, 5 per cent CO_2. Before you proceed further be dead sure that the gas sample was properly taken. Is the open end of the gas pipe at the center of the gas flow in the last pass? You know how the baffles are arranged in the boiler and where they are located. You can judge about how the gases will flow from the bottom of the last baffle to the gas exit from the boiler. You can find the approximate center of the gas flow, if you are uncertain about it, by probing for it with the gas pipe and working the Analyzer. The center is the place where you get the highest CO_2 and the most pronounced fluctuations in the percentages. If you get uniformly low percentages and there are no marked changes when the furnace doors are opened and closed, it may be that the baffling has broken down or some other abnormal circumstance has short-circuited the gas currents out of their normal channels.

Now, what does this 5 per cent CO_2 mean? And why are we getting 5 per cent instead of 14 or 15?

The CO_2 percentage indicates the volume of excess air flowing through the furnace and the passes of the boiler—the ratio between the air that is taken for a useful purpose in burning the coal and that which is taken to the wasteful end of cooling the furnace gases. That is all that it does indicate and its indications are only approximations. We might determine the air excess much more accurately

by finding the percentage of free Oxygen with the Gas Analyzer. The objection to the Oxygen analysis is that it takes time and we do not have the time for it. We want data and I have already shown how essential speed is to securing that data. Some of it will get away from us if we do not work the Analyzer about once a minute. It will take five minutes to determine the Oxygen. When you work the CO_2 percentage up to 12 or 15 it will be time enough to analyze for Oxygen and CO. Don't spend a minute on those gases until you do.

Why does the CO_2 percentage indicate the excess air?

The air normally carries about 20.7 per cent Oxygen by volume. When Oxygen combines with Carbon in the reaction of combustion, both the Oxygen and the Carbon disappear as such. The solid Carbon unites with the gas, Oxygen, and another gas results which the chemist has labeled "CO_2." He resorts to the formula because it tells him precisely of what the gas is composed—that it is one part Carbon (C), and two parts Oxygen (O). And moreover the Chemist is too blamed lazy to write out the full name of the gas, "Carbon Dioxide."

It is a curious fact that when we take a given volume of Oxygen and add to it a given bulk of coal, Carbon, to form CO_2, the resulting gas exactly equals the volume of the original Oxygen. Here is a case where we can take a pail full of fluid and add a solid to it without overflowing the pail. I must ask you to accept this established fact as "gospel" because the space is lacking to explain it.

Now, remembering that the air contains 20.7 per cent Oxygen, let us consider an illustration:

Suppose we have a quart of milk that is 20.7 per cent cream. We add a quart of water and our two quart mixture is 10.35 per cent cream. There is the same quantity of cream as in the first instance, but the diluting water reduces the percentage of the cream in terms of the total milk and water mixture. If we add two more quarts of water giving us four quarts of weak milk in all, the mixture will be 5.175 per cent cream. The water excess would be three times the original milk and cream volume, or 300 per cent. If you do not understand this thing your

milkman will explain it to you. Doubling the air supply works the same mathematics on CO_2 that doubling the water added works on cream.

It should now be understood why the lower we go in the scale of CO_2 the greater will be the waste that the drop of each succeeding per cent indicates. For example, if we drop from 16 per cent CO_2 to 10 per cent, the loss due to this drop of 6 per cent will be around 6 per cent in fuel, while the loss in dropping from 10 per cent to 6 per cent is near 12 per cent in fuel, and in dropping from 6 per cent to 2 per cent the loss is 57 per cent of the fuel. Theoretically the loss becomes total at 1.5 per cent CO_2 the volume of excess air heated being then so great that it would be impossible to boil the water in the boiler. The charts and tables presented will show the CO_2 and excess air relations in a more graphic and detailed manner.

It must be remembered that all such charts and tables are based upon an assumed set of conditions. In the present instance the fuel is assumed to be pure Carbon, which fuel never is, and the stack temperatures are assumed to be constant at 500 deg. Fahr., which they never are. The higher the stack temperatures the hotter we are heating the excess air and the hotter we make it the more fuel we are wasting.

It is not pretended that any engineer can actually compute his gains and losses from the table submitted or that the figures given indicate the excess air in any instance. As stated, the table applies to pure Carbon only. With such fuel the theoretical CO_2 would be 20.7 per cent by volume. When a bituminous coal is burned the theoretical CO_2 will be less, depending upon the percentage of Hydrogen in the combustible, probably somewhere between 17 and 19 per cent, as against 20.7 per cent.

The fuel waste in your plant may be more or less than the figures given in the table, but it will not be very far from them. They will serve as a sufficiently accurate guide for all practical purposes and you may, if you wish, base a bonus system upon them and reward your firemen according to their CO_2 deserts.

Instead of presenting many tables applying to many coals,

I therefore present but one, and it, as I have stated, applies to straight Carbon:

CO_2 AND FUEL LOSSES.

Pct. CO_2	Pct. Preventable Fuel Loss.	Pct. CO_2	Pct. Preventable Fuel Loss.	Pct. CO_2	Pct. Preventable Fuel Loss.
15	0.0	10.0	5.69	5.0	22.79
14.8	0.148	9.8	6.04	4.8	24.21
14.6	0.305	9.6	6.40	4.6	25.76
14.4	0.470	9.4	6.78	4.4	27.44
14.2	0.635	9.2	7.18	4.2	29.29
14.0	0.808	9.0	7.58	4.0	31.28
13.8	0.990	8.8	8.02	3.8	33.58
13.6	1.17	8.6	8.47	3.6	36.08
13.4	1.36	8.4	8.95	3.4	38.87
13.2	1.54	8.2	9.44	3.2	42.01
13.0	1.75	8.0	9.66	3.0	45.28
12.8	1.95	7.8	10.51	2.8	49.64
12.6	2.16	7.6	11.09	2.6	54.34
12.4	2.38	7.4	11.70	2.4	60.32
12.2	2.60	7.2	12.34	2.2	66.30
12.0	2.84	7.0	13.02	2.0	74.00
11.8	3.08	6.8	13.74	1.8	83.56
11.6	3.33	6.6	14.49	1.6	95.45
11.4	3.59	6.4	15.30	1.4	
11.2	3.86	6.2	16.16	1.2	
11.0	4.13	6.0	17.09	1.0	
10.8	4.43	5.8	18.06	.8	
10.6	4.72	5.6	19.12	.6	
10.4	5.03	5.4	20.25	.4	
10.2	5.35	5.2	21.47	.2	

I could not give you a table that would exactly apply to your coal because I do not know what coal you are burning and, lacking an analysis showing the relative percentages of Carbon, Hydrogen and Sulphur, I could not give you a table even if I knew the origin of the coal. And even if you contract for coal of a definite B. t. u. value and definite ash content, you will not know short of a daily coal analysis

whether you are or are not getting the coal for which you contracted. When you adopt the modern method of paying for heat units instead of for fuel by the ton you will come nearer getting what you pay for.* Until you do adopt that method, you can just roll up your pious eyes when you see the coal wagon coming and pray that there may be a few heat units in it.

The table assumes the fuel to be pure Carbon and that the temperature of the escaping gases is constant at 500 deg. Fahrenheit. On this assumption the loss would become total at a fraction above 1.5 per cent CO_2. The table also assumes the entire absence of CO.

It is plain that the temperature would not remain constant—that it would decrease both at the furnace and the exit of the boiler with the decrease in CO_2. While the fall in temperature would affect the table it may be stated that the figures given will very closely apply in actual practice where the fuel used is a low volatile, high carbon coal.

The table further assumes that 15 per cent CO_2 is the limit beyond which it is not safe to go in good practice. There is a loss of 3.1 per cent due to excess air between 15 per cent and the theoretical limit of 20.7 per cent CO_2, which the author has presumed to figure as non-preventable.

CO_2 AND AIR EXCESS.

Pct. CO_2.	Pct. Air Excess.	Pct. CO_2.	Pct. Air Excess.
15	38	6	245
14	47.8	5	314
13	59.2	4	417
12	72.5	3	590
11	88.1	2	935
10	107	1	1970
9	130		
8	158.7		
7	195.7		

To determine the percentage of excess air for any given

*For a discussion of this subject, see "How to Cut Your Coal Bill." by the Author. The A. W. Shaw Company, Chicago.

percentage of CO_2, as for example, 5.4 per cent, proceed as follows:

Subtract the observed percentage (in this case 5.4), from 20.7, divide the remainder by the observed percentage and multiply by 100. This gives the volume of excess air. At 5.4 per cent CO_2 the excess air is 283.33 per cent. In rough figures the preventable fuel waste may be computed by allowing 1 per cent of fuel loss for each 12.11 per cent of air excess above 38 per cent. This figure is quite as accurate as the one commonly applied to feed water, viz.: one per cent of the fuel lost or gained for a change of temperature in the feed water of ten degrees.

But to return to the specific problems before us in testing the gases from your furnace and "B. & W." boiler.

What did the 5 per cent CO_2 mean?

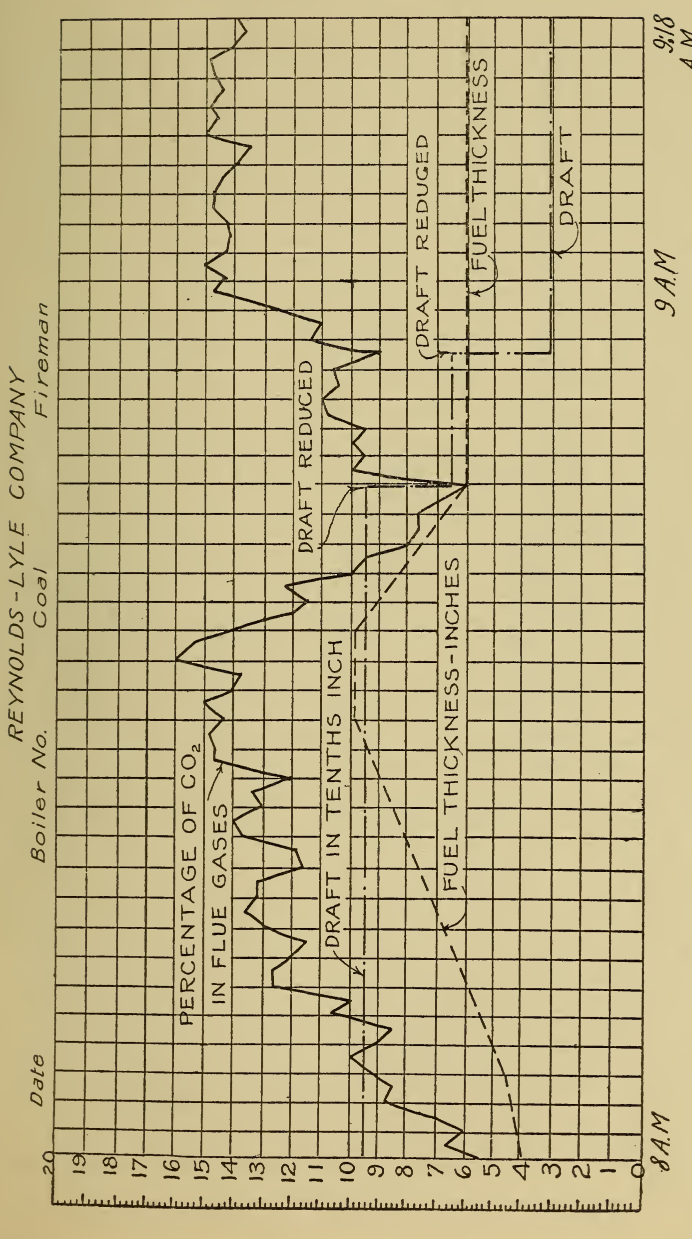
It meant that you were heating 314 per cent excess air and that you were uselessly wasting 22.79 per cent of your fuel; that for every 100 cubic feet of air that you were using to burn the coal you were taking in and heating to the temperature of the uptake gases an additional 314 cubic feet. You were using in one boiler furnace almost enough air to operate three of them.

Now, if we can find why and where the excess air is getting in, we will know the exact reason for the fuel waste and we can devise a remedy. The draft gage says that there is a negative pressure, or a "draft" of 21 hundredths of an inch over the fire in the furnace. I am just assuming that draft for the purpose of the illustration. The draft might be anything.

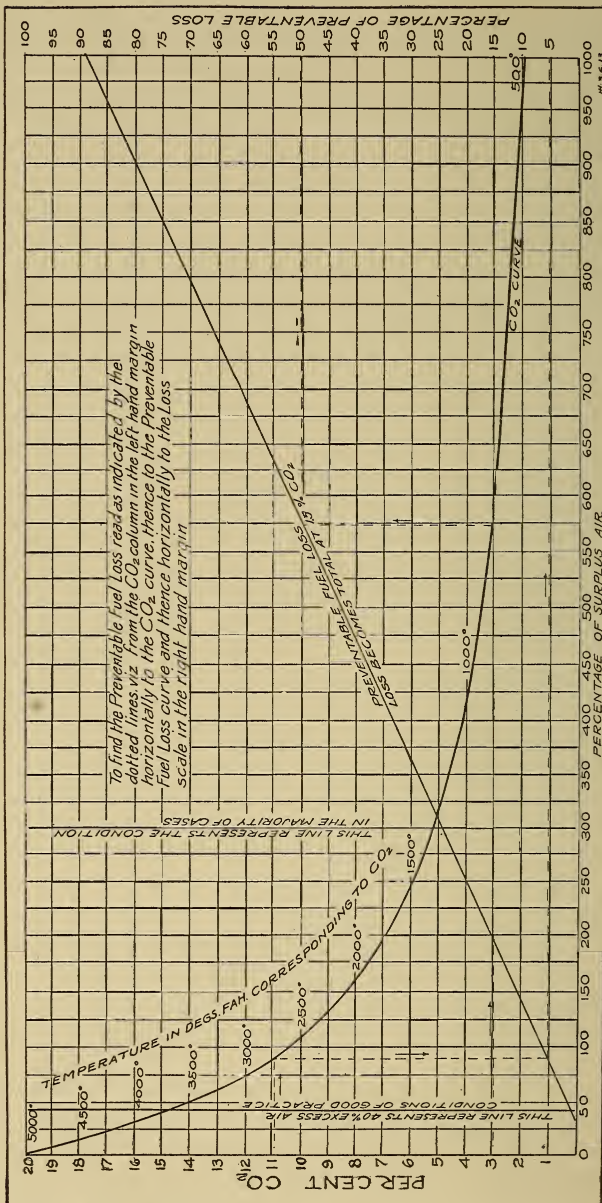
We now turn to the fireman, the favored fellow who is trusted to handle your money with a scoop shovel. He has been making steam without thinking. We must wind up his "think" clock and set it ticking.

He has been putting some more coal on the fire and we catch him in the act of closing the furnace door. We say to him:

"Why did you shut the furnace door? Why not leave it open? Why not take the thing off altogether and sell it for old iron? Every time you close the door you have to open it again. This takes time and means work and may burn your fingers."



In making a study of the kind under discussion, be sure to preserve the data. Plot curves for the CO_2, Drafts and Fuel thicknesses. These will show in graphic form the relations you are seeking to discover.



Curves showing the relations between CO_2, furnace temperatures, excess air and fuel loss.

The fireman looks at us quizzically. He thinks we are joking him. We press him for an answer and he delivers a pointed lecture on the economies of combustion.

"Do you see that steam gage up there?" he asks us, "Well it is my business to keep the arrow pointing at 100 pounds. How long could I hold steam if I did not close the door? The cold air would rush in and cool off the furnace. Everybody knows that. Sure, you must be 'joshing' me to ask such a fool question."

And so we see that the fireman knows about the damaging effects of cold air. The trouble with the fireman is that he does not continue his line of thinking and apply his cold air theories to the thin places and the holes in his fire.

We explain to him that the Gas Analyzer is an instrument for measuring the cold air that is going through his furnace and he immediately understands what the curious looking thing, that he has been eyeing with suspicion, has to do with his work. We now call his attention to the cracks and holes in the fuel bed and force him to admit that cold air is flowing through them, also that the cold air so taken is just as damaging to steam and efficiency as the cold air that flows through the open fire door. We ask him to take a light rake and level off the fuel. To do so he must break up the islands of coke and close the cracks and air holes. When he has finished we take the "calibrated" fire hoe and discover that the "fire" is four inches thick. We also note that stopping the air leaks has jumped the draft from 21 hundredths of an inch to something higher, say 30 hundredths. We try the Gas Analyzer at once and it reports 7 per cent CO_2. Referring to the table above we find that the air excess has been reduced from 314 per cent to 195.7 per cent. Subtracting the last figure from the first one we find that we stopped an air excess of 118.3 per cent by raking the fire and closing the cracks. We reduce the fuel loss from 22.79 per cent to 13.02 per cent. We take great pains to explain this to the fireman and we make him admit that the fire is now in better condition than before he raked it.

The Analyzer has told us that we are on the right track but that we still have some distance to travel. There are

no cracks in the fuel now, but we are not getting enough CO_2. Possibly the fuel is a little thin for the draft that is being applied to it. The thinner the fuel the easier it is for the draft to pull excess air through it. On this assumption we have the fireman thicken the fuel bed gradually, measuring it at intervals with the hoe. We get as high as 8 per cent CO_2 and there we stick. We have a "peach" of a fire but we cannot push the air excess any lower.

We next move the gas pipe sampling tube to the middle blow hole of the first pass of the boiler and take a sample. We must grab this sample very quickly because when the tube is heated to an oxidizing stage it will take oxygen from the gases we are pumping through it and this will affect the result of our analysis. We find 14 per cent CO_2, under the same furnace conditions that had been giving us 8 per cent at the last pass of the boiler. There is a thundering leakage of air between the first sampling point and the last one—110.9 per cent. We now go after that boiler setting with the candles. We find leaks at all of the localities suggested in the previous chapters. The leaks about the headers into the first pass are particularly serious. We get none of this last mentioned leakage when sampling from the first pass because the sampling tube was toward the rear of the pass and the cold air was flowing in at the front of the pass. It did not mix with the gases until the second pass was reached. We got the full returns from it in the last pass, together with that of all the rest of the air leakage about the boiler setting, which the candles tell us must be considerable.

We go after these air leaks now with an understanding of what they really mean to efficiency and we keep after them until two snap-shot gas samples, taken one at each of the extreme boiler passes with the least possible intervening interval, show the same percentage of CO_2. When you learn how rapidly the gases change within certain limits you will understand why speed in the operation of the Analyzer is necessary if you wish to accumulate data.

When we know that the setting is properly tight it will be just a question of pursuing the study until we find the

exact conditions of draft, fuel thickness, etc., that will yield from 14 to 15 per cent CO_2. When we find these conditions we have "arrived" and it is just a question of keeping at it until we do find them. The process of finding is one of "cutting and fitting and trying."

After the standard thickness of the "fires" has been determined, place permanent marks on the fire door liners for the guidance of the fireman. Instruct him to carry the fires on these marks at all times, as far as possible, and to control the rate of combustion with the boiler damper.

Thickening of the fuel may aggravate your clinker troubles and you might lose here all that you would gain by the thickening. It is taken for granted that you will have sense enongh to use judgment in this matter and in all others.

As you increase the percentage of CO_2 the furnace temperature will rise rapidly. The charts elsewhere show the relation of CO_2 to temperatures and of the temperatures to the excess air. The steam will go up with the rise in temperatures.

About two years ago a committee was appointed by an engineering society to investigate CO_2 Recorders. It reported adversely and cited the fact that an increase in CO_2 was usually followed by a rise in stack temperatures. Hence it reasoned that high CO_2 did not indicate efficiency, but the contrary, and that all "CO_2 Apparatus" was to be avoided as promoting waste rather than efficiency.

The "Chimney Waste" cannot be determined from the uptake temperatures alone or from these temperatures considered in relation to the initial furnace temperatures. The pyrometer does not count heat units. It measures intensity without regard to quantity. A pint of water at the boiling point contains far less heat than a barrel of water at a far lower temperature. And so as regards chimney temperatures it makes a lot of difference whether the pyrometer is reporting on a pint of gas or a barrel of it. The heat loss in the uptake is determined by multiplying the temperature into the quantity of air and gases heated. You can stand a reasonable increase in uptake temperatures as you rise in the CO_2 scale because you are reducing the

quantity heated faster than you are increasing the temperature.

A Chicago engineer complained that he could not get 14 per cent CO_2 without shutting down his plant. It was found that he reduced the draft to increase the CO_2, and, of course, in doing so he reduced the steaming capacity of his boilers. Now had he followed the method indicated in this chapter he would have obtained an increased capacity. Had he stopped the air leaks and improved the conditions in his furnaces he would have raised the CO_2 and he would have had steam to sell.

There is a relation between the draft that should be used and the resistance of the fuel on the grates. I have taken as high as 16 per cent CO_2 with no more than a trace of CO from marine boilers under forced draft during a speed trial at sea. The idea that high CO_2 calls for low draft is one of the many fictions current relating to combustion analysis. You can get high CO_2 with any draft in reason, either high or low, provided the draft and the fuel resistance are in proper relation.

Bear in mind that the CO_2 percentage indicates the ratio of the air used to the air that has not been used.

I can get 18 per cent CO_2 from a stinking old tobacco pipe that is one of my prized possessions, but if I should take the fire out of that pipe and put it under a boiler I couldn't get any steam with it.

"Your steam plant is operated for the purpose of running your power plant and not for the purpose of making CO_2." Why, sure. I admit it. And if you do the right thing by that steam plant the more CO_2 you make the more steam you will get from unit quantity of fuel and the more steam you make the less unit quantities of fuel you will burn.

These propositions have gone past the point where they require defense. They are proved propositions. The physical laws that govern combustion take sides with them.

The CO_2 percentage is an index of efficiency and not of capacity, altho, as I have shown, it may be taken as a measure of capacity if the draft is not decreased to secure the increase in the CO_2. But however the increase in the

CO_2 is attained, it is a measure of efficiency—the volume of heat-nullifying cold air taken in comparison with the volume of heated gas developed by the process of combustion.

Everything that I have said so far is based upon the assumption that there is no CO accompanying the CO_2. When the air supply is insufficient or improperly distributed, there will not be enough Oxygen to convert all of the Carbon to CO_2. Some of it will have to be satisfied with one part of Oxygen instead of two parts. The Carbon will be half burned and CO will result. CO is the "Bob-tail flush" of combustion.

When Carbon is burned to CO_2, 14,500 units of heat energy are released in the furnace. When it is burned to CO, 4,400 heat units are released and the remaining 10,100 continue unreleased in the CO and with it ride up the chimney. So that when we are basing a judgment as to efficiency upon CO_2 percentages we must know whether or not CO is present and if it exists we must qualify our judgment.

There is as much Carbon in a molecule of CO as in a molecule of CO_2, so that if the gases show 9 per cent CO_2 and 1 per cent CO, 90 per cent of the combustible has been completely burned and 10 per cent partly burned. This 10 per cent carries away 10,100 heat units per pound of Carbon taken out of an original 14,500, so that the actual fuel loss represented by the CO in such case would be 10,100-14,500ths of 10 per cent. From this statement you will be able to see how the following formula is derived:

To find the loss due to CO in percentage terms of total carbon burned divide the percentage of CO by the sum of the CO_2 and CO percentages, multiply by 100, divide by 145 and multiply by 101.

Applying this formula to a case of 9 per cent CO_2, and 1 per cent CO, we find that the fuel loss due to the CO is 6.9 per cent.

There has been much discussion in the engineering journals as to the relative importance of the CO_2 and CO determinations in flue gas analysis. Some engineers even

go so far as to recommend an analysis for CO every time the CO_2 determination is made. The main objection to this is that it takes a lot of time and means a lot of really unnecessary work. The sensible method is to first find out how to secure the desired percentage of CO_2 and then to check the gas sample for CO. It will be found in most cases that when the CO_2 percentage has been made right the Oxygen and CO will fall into line and be right also. Of what concern is it to us if CO does in fact exist with a low percentage of CO_2, say 6 per cent? We don't want the CO, of course, neither do we want the 6 per cent CO_2, consequently we are not concerned to find the reason why CO exists when we have 6 per cent CO_2. We want 14 per cent CO_2 if we can get it, and we want no CO with that 14 per cent. We might stand for a trace of it, but not for much more. To wipe out the undesired CO it may be necessary to increase the excess of air and thereby lower the CO_2. But the CO may not owe its presence to lack of air. It may be due to lack of mixture or certain other causes that will land us in rather deep theory if we attempt to consider them.*

Low CO_2 may be caused by lack of air as well as by a surplus of it, but the surplus is the cause in almost every instance. Whatever the cause for a drop in CO_2 the furnace temperature will drop with it. We may find CO with any percentage of CO_2. Suppose that the "fire" is very thick and perhaps "dirty" in one portion of the furnace. This condition would result in the formation of CO because not enough air could pass through the thick and dirty "fire" to reduce the Carbon to CO_2. Now if there are air leaks in the fuel on another portion of the grate a large excess of air would be passed through them and we would have CO in the flue gases in the presence of an excess of air.

I have heard it stated that we cannot get more than 8 or 10 per cent CO_2 without inviting CO in considerable quantity, but this is not in accordance with my experience. I do not consider that we are courting danger from

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See "The Chemistry of Combustion," by the Author.

CO until we have reached about 15 per cent CO_2. This statement is made upon the assumption that the boiler setting is tight and that there is sufficient draft for proper combustion. If the setting is leaky we might have to indulge in extremely thick "fires" to raise the CO_2 percentage and this, as explained in the preceding paragraph, might produce CO while the air taken in through the setting would, of course, lower the CO_2 percentage by diluting the gas volume.

If we are engaged in experimental or research work we must concern ourselves, not only with the CO_2, but with the CO and SO_2 and with the Hydrogen and Methane as well. The operating engineer is not engaged in research investigations. He is engaged in making steam and he wants to make it as economically as possible. His plant is not operated under test conditions, but under severe working conditions. Hence, he must adopt in gas analysis. as in everything else, the methods that are applicable to the every-day grind of an every-day steam power plant. And he will secure amazing results if he will begin with CO_2 and stick to CO_2. I do not mean that he should never make CO investigations. I insist that he *should* make them, but that he should select the right time for doing so and that time will not arrive until he has first placed his furnaces upon a proper CO_2 basis.

It is a significant fact that some of the engineers who have accomplished the most with flue gas analysis, who have made savings as great as 40 and 50 per cent, have been non-technical men who have never gone farther in gas analysis than the CO_2 determination. They have pursued air leaks and studied draft regulation. They have "taken chances" on CO and it is not likely that much of it is to be found in their furnace gases. And I would back one of these men every time for real results in the boiler room against the man who is all "technical"—who is a mile long on theory and an inch long on practice. When such a man gets into the boiler room he will begin with CO studies and he will have to resort to formulae and other things that are mystifying. In other words, his work will be of a laboratory kind and of a research nature. And as

a result of his methods a shroud of mystery will be thrown over the whole performance. Nobody in the fire-room will take any interest in the thing, hence no benefit will result from it.

It will help very much if the engineer who is undertaking flue gas analysis will acquire some of the theory on which his practice is based—if he will learn a little of combustion chemistry, but it is not *essential* that he should know anything at all about the theory or the chemistry of it. It *is* essential that he should follow right methods and if he does this he will produce right results.

The marksman need not know the chemical properties of the powder in the cartridge before making a bull's-eye. Neither is it necessary that an engineer or fireman should know what CO_2 really is, or *why* it is, before he begins work with a Gas Analyzer. A man who can read a thermometer scale can read that of a Gas Analyzer and if he will keep after the Analyzer until he gets the right reading he will get results that will surprise everybody about the plant—most of all the Manager.

Don't carry a sample of gas in a bottle from the boiler room to the laboratory. Make your study of furnace conditions right at the furnace and make enough determinations to acquire some real data. When you have finished your investigations in the boiler room, say at the end of an hour, or at most two hours, reduce your data relating to CO_2 percentages, fuel thicknesses and drafts, to curves upon a chart and this will serve to show the very relations you have been seeking to discover. Knowing these relations you may proceed to standardize the operating methods in your boiler room and prescribe a rule of action for your firemen.

I think it will now be plain how the answers to most of the questions proposed in the first chapter may be worked out.

When you know how much fuel the furnace is wasting by heating excess air, how much it is dropping in the ash-pit and how much CO it is sending up the chimney, you come very near knowing the efficiency of that furnace.

Employ the draft that will carry your load and pro-

duce the highest percentage of CO_2 without CO. You must determine by actual experiment what that draft really is. With bituminous coal it will probably be in the neighborhood of 30 hundredths of an inch over the fire. The more ash the coal contains the more draft you will have to use and the lower the maximum percentage of CO_2 that you will be able to get. Control the draft with the boiler damper rather than with the ash-pit doors.

Calibrate all of your dampers. To do this connect a differential draft gage between the damper and the boiler. Place the damper in the extreme closed position. Then open it gradually. Mark the position of the damper when the draft gage is first affected. Continue opening the damper until the gage stops registering an increment in the draft. Mark this position and adjust the damper to work between those two positions. The slightest movement of the damper will then register its effect at the furnace and the effect will be proportional to the movement of the damper. You will meet some surprises when you calibrate your dampers. You will find in some cases that the damper is "wide open" when it is partly closed and in others that it is "partly closed" when it is wide open. A great deal will depend upon how the damper is hung and the direction of the normal gas flow with respect to the normal open position of the damper. It is of the highest importance that the main breeching damper should be calibrated before you hook it up to an automatic damper regulator.

The advantages of a damper regulator are liable to be overestimated. A proper regulator will assist in securing economy. An improper one may actually increase the coal consumption although it may produce a perfect steam curve on the chart of the recording gage.

Regulators may be divided into two general classes for the purposes of this discussion:

1. The machines that move the damper a little when there is a slight change in the steam pressure, the movement of the damper being proportional to the change in pressure.

2. The machines that swing the damper from the wide open position to the closed one when the pressure rises

and from the closed position to the wide open one when the pressure falls.

We must vote for the Regulators of the first class mentioned because those of the second class do not meet the requirements of economial combustion. When the damper is wide open the furnaces will be getting too much air and the percentage of CO_2 will fall. When the damper is closed the furnaces will not get enough air and CO will be formed. Machines of the first class may not make as perfect a steam curve as those of the second, but they will show economy where the others may produce waste.

To equalize the draft among the boilers, first see that the fires are all in standard condition—of the same thickness without air holes and free from clinkers. Then adjust the boilers' dampers so that all of the furnaces will have the same draft—your standard draft, whatever it may be. Thereafter you may regulate the draft to meet the load by shifting the main breeching damper. The draft will vary with changes of barometer, so that it may be necessary for the fireman to make certain damper adjustments every day, but these adjustments, so far as possible, should be confined to the master damper in the breeching and they will consist in altering the maximum open position of the damper for the day.

I have shown how the air leakage through the setting may be measured by shifting the sampling pipe from the last pass to the first pass. Be sure that the fire is in good condition when the test is made and make the two determinations very close together, otherwise some condition affecting the air excess may intervene in the furnace and spoil the comparison. If the fuel on the grates is peppered with thin spots and air holes, a sample taken from the first pass may be misleading. Suppose for example that there is a large air leak in the fuel bed immediately below the intake end of the sampling pipe. A tornado of air will rush up through it and the Analyzer will report low CO_2 as a result of that air, whereas the actual average from the furnace might be a reasonably high percentage of CO_2. And conversely, if you should take gas from a section of the furnace in which the fuel conditions were first class, while in all other

sections they were poor, the report would be too high. Plug the air leaks in the setting and you will then have no occasion to measure the air flowing through them.

The other questions relating to excess air may be answered by following the same general method of procedure.

Don't neglect the marks on the liners of the furnace doors when you have learned how thick the particular coal you are burning should be carried on the particular grates you are using.

The coal best adapted to your conditions is the coal that you can burn with the least surplus of air. You are limited, of course, by the fuels available in your market and you may be justified by price considerations in using the fuel not best adapted to your conditions. In planning a boiler plant the fuels available should receive more consideration than they are usually accorded and the equipment purchased should be selected with reference to the fuel that you ought to burn.

Should the coal you are using be fired dry or wet for greatest efficiency? This will depend upon circumstances and the question will be answered by the Gas Analyzer.

It takes heat units to evaporate the water that you have applied to the coal and the business of these heat units is to evaporate the water in the boiler. We must make an entry on the debit side of the ledger.

When a shovelful of wet coal goes into the furnace, the first thing that happens is the evaporation of the surface moisture clinging to the coal. This is followed by the decomposition of the resulting steam into its elements, Oxygen and Hydrogen. The Hydrogen is next ignited and burns back again into water, returning to the furnace the exact amount of heat abstracted in the operation of decomposition. Some of this heat will be lost by radiation, more of it will be discarded to the chimney and some of the Hydrogen may escape without being consumed. There is, accordingly, a net loss by this operation. There is another debit.

But there are credit entries also. Combustible gases are being evolved from the fuel. The Hydrogen flame assists in igniting them. When water and incandescent coke come into contact with each other there is an evolution

of CO as well as of Hydrogen, the Oxygen of the water uniting with the Carbon of the coal to form Carbon Monoxide. This gas rises into the furnace chamber and burns with the Hydrogen. The area of combustion is extended and we have a flaming furnace through which no combustible gas can pass in the presence of Oxygen without burning.

Fine coal, when thrown into the furnace, tends to "pack," particularly if it is dry and there is much ash and foreign matter in it. If it is wet, the water when it is converted into steam, will loosen the packed coal permitting the air to flow more reaidly through it. As a result the coal will burn more uniformly and you will burn more of it because there will be less combustible in the ash and clinker and much less combustible carried over by the draft into the combustion chamber. There will be fewer cracks in the fuel bed and the coal will be burned with a great deal less excess of air.

It is impossible to burn some fine coals without wetting them. You can burn any fine coal with better results and more satisfaction if you turn the hose on the coal pile. Do you prefer to smoke your cigars damp or kiln dried?

The grate surface is just right for highest economy when you can carry a proper fire upon it without blowing off the safety valve. The fire is not proper if it is so thin that too much unused air will pass through it and if you have too much grate surface you will either have a great excess of air or a popping safety valve.

Smoke is due to one of four causes or to a combination of two or more them, viz.:

1. Lack of air; 2, lack of mixture; 3, lack of temperature, and 4, lack of space. Now before blowing yourself to steam jets or some other cure-all device for preventing smoke it would be wise to discover why your chimney is smoking.

If the boiler setting is tight and the gases show no more than 12 per cent CO_2, there is an abundance of air and nothing will result by admitting more of it except to lower efficiency.

If the furnace is white hot there is plenty of temperature.

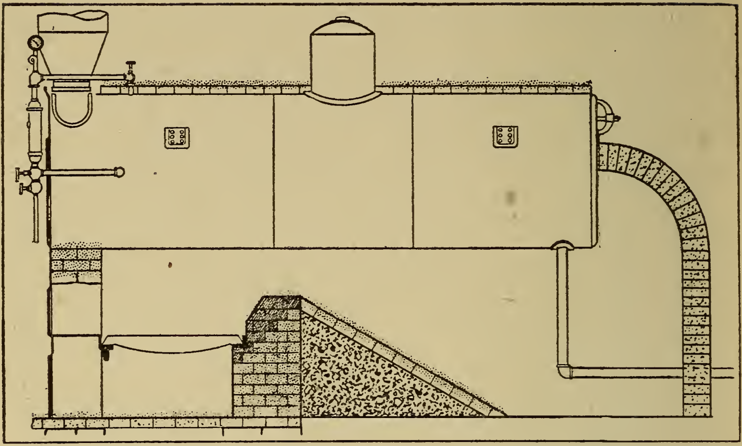
If there is an abundance of air (free oxygen) in the gases and you find CO, the trouble is insufficient mixture. The air is being taken in at the wrong place, or the design of the furnace is such that the air taken is not caused to mix with the combustible gases. The difficulty may be remedied or ameliorated by the use of mixing piers or arches.

Lack of space is probably the most common of all the causes of smoke. The grates must be at such a distance below the heating surfaces of the boiler that the flame will be burned out before the relatively cold metal is reached. Take any cold substance, a piece of glass for instance, and hold it in the flame of a gas jet. There will be a deposit of carbon at once. If your smoke is caused by the snuffing out of the flame upon the cold surfaces of the boiler you will find very little CO in the gases, perhaps none whatever, although there may be a great quantity of soot.

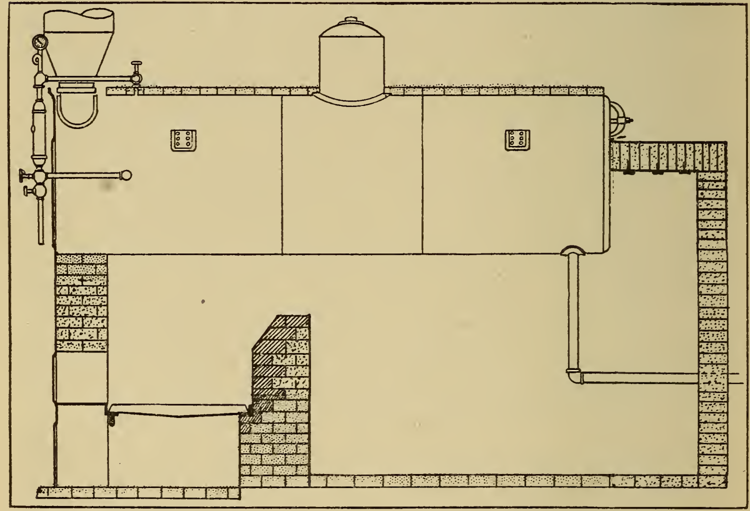
"Smoke means waste," of course, but as I have already pointed out, there is very little fuel value in the finely divided carbon that colors the chimney gases. A chimney that is making no smoke at all may be throwing out more actual combustible gas than one that is a bad smoker.

But assuming that there is an appreciable quantity of real combustible in the chimney gases. Can we eliminate it without sustaining a loss that exceeds the saving? If you save $2.00 by burning up the combustible gases and lose $4.00 by heating the excess air that is incidental to the process, how much of a gainer are you? To burn soft coal smokelessly is a simple matter, but to burn it smokelessly and at the same time economically is up another street altogether. If the men who are selling "smokeless furnaces" were compelled to put their devices up against a Gas Analyzer, nine-tenths of them would go out of business.

There was a time when the Smoke Inspector was not concerned in the methods by which you attained smokelessness. You could equip with steam jets or any other make-shift, wasteful thing so long as you stopped violating the ordinances. And the result of this was that the Inspector was an Ishmael among the power producers. His hand was against every man and the hand of every man was against him. It is a cheerful sign that the times have changed when



The way your R. T. boiler is "set" and the wrong way to set it—the grates 28 in. from the boiler shell and the combustion chamber partly filled in. You can't help smoking.



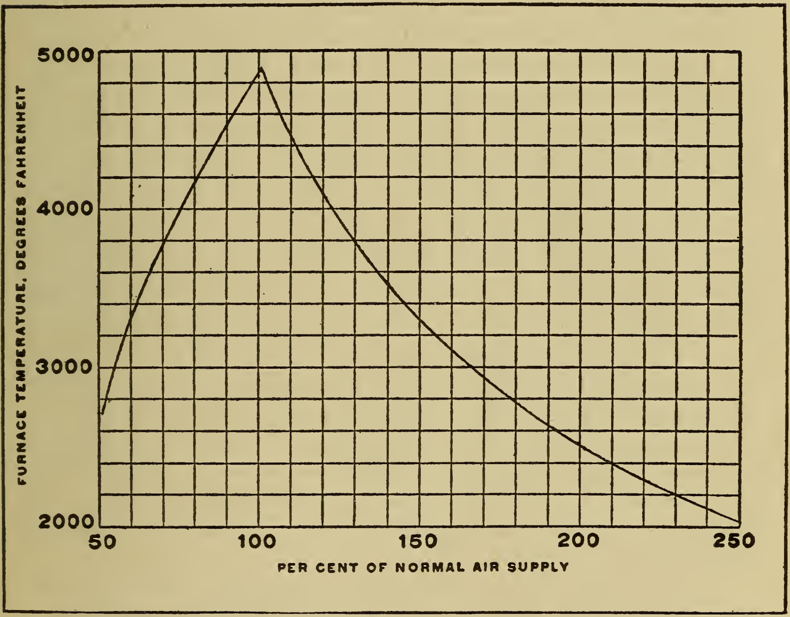
The way your boiler should be set to burn bituminous coal—the grates about 48 in. from the boiler shell. A "roomy" combustion chamber. Note the flat arch at the rear.*

*For a detailed discussion of smokeless furnaces see "Combustion and Smokeless Furnaces" by the author.

the Inspector now visits the plant in the role of a helper rather than that of a fault finder. He comes to advise and while he insists upon smokelessness, he wants to see you get smokelessness done up in a wrapper of efficiency.

And don't assume that your boiler plant is efficient because your chimney is not smoking. Show me a chimney that never makes a trace of smoke and I will show you a plant that is not burning coal efficiently.

The territory between no smoke—no combustible of any kind in the gases—and highest efficiency is fixed by very



The highest furnace temperature is attained when the theoretical air supply (100 per cent) is applied. Furnace temperatures fall very rapidly, as shown, when the supply is increased or diminished from this figure.

narrow boundary lines. Let us draw a horizontal line and consider it as lying in the plane of highest efficiency—complete combustion with the minimum supply of excess air. Above this line is the territory of unnecessary excess air, and below it the territory of air deficiency. The higher we go above this line the more of a "hot air factory" we are run-

ning. The farther we go below it the more smoke and CO we are making. If we remain in the neighborhood of the line, fluctuating furnace conditions will place us first on one side of it and then on the other. There will be periods of no smoke, succeeded by periods of slight smokiness. Conditions like this at the top of the chimney usually point to economical furnace operation. If there is no smoke at all we have no means of knowing by mere stack observation to what extent the furnace may be indulging in excess air.

The Gas Analyzer will answer any strictly combustion question that may be propounded to it. It applies to Gas Producers and "Internal Combustion Motors," but its uses in these connections cannot here be considered by the author.*

The higher the percentage of CO_2, in the absence of CO, the higher the initial furnace temperature. And as a general proposition, the higher the furnace temperature the greater the efficiency. Extreme temperatures are destructive of brick work but they are not liable to damage the tubes or sheets of the boiler, provided there are no deposits of scale, mud, oil or other materials that will prevent intimate contact between the water and the metal. Some engineers are afraid of burning up their boilers, and boilers *are* sometimes "bagged" and burned but the trouble can invariably be traced to scale or oil. Why you can take a paper oyster pail, fill it with water, set it in the blue flame of a gas burner and boil eggs without marking the paper except along the folds where the water is not in actual contact with the paper. If you will try this experiment you will cease to be afraid of high temperatures, but you will be more than ever afraid of scale and oil. You simply can't burn a clean boiler tube if there is water in actual contact with it.

High temperatures promote smokelessness, because temperature is one of the requisites of smokeless combustion. When the furnace salesman approaches you, find out how much CO_2 he will guarantee without making CO,—not how much water he will evaporate. If he guarantees high CO_2 he is guaranteeing furnace efficiency and incidentally agreeing to meet one of the conditions of smokeless combustion.

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*See Volume IV, "The Chemistry of Combustion" by the Author.

CHAPTER V.

HOW TO KEEP THE WASTES STOPPED.

When the levee breaks along the lower Mississippi they stop the leak with sand bags and niggers. And they stay on the job as long as there is high water, because it is one thing to stop a leak and another thing to keep it stopped. It is always high water in your boiler room. If you want fuel economy, first stop the fuel wastes and then sit on the stopper. It is one thing to attain efficiency and another thing to maintain it. If you kiss the fireman and say "good-bye" when you are through with your stopping operations, every waste, within the man's control, that you have killed will resurrect itself and renew its operations.

Neither the Manager nor the Engineer can stay in the boiler room and watch the fireman. Some means must be devised for keeping a check upon him. Human nature will do better work, no matter what the field of endeavor, if it is completely surrounded by some effective checking system. You know this and you have time clocks and various other checking devices in your factory. You check the output of each man and machine, both as to quantity and quality. You inspect operations in the factory until you are black in the face, but the black-faced man in the boiler room knows that his operations will not receive inspection. Hence he is a careless and wasteful individual, just as I have described him and exactly as you know him.

I assisted in the "spotting" and stopping operations in an Ohio boiler room last November. We calked the boiler setting and jacked the CO_2 up from 4 per cent to 14 per cent. We showed the fireman what the air leaks in the fuel bed had been doing to efficiency and we made him understand what we were saying. The meeting was adjourned after an interesting hour and a half and I returned to the office with the Manager. We talked for a little while and

then I said, "I'll bet you five dollars we can go down to the boiler room right now and find the same old 'rat holes' in the fire." We caught the fireman unawares and we found them. It was laughable to see the way the man unlimbered himself to stop them. He had neglected to pull the calking out of the air holes in the boiler setting, which was probably an oversight, for in every other particular he had reverted things to their original condition. My friend, the Manager, jettisoned his entire cargo of religion on the spot and swore like a mule driver.

It takes some of the stuff that sustained the martyrs to deal with a fireman. It won't help to swear at him and refer to his ancestry. Neither will it serve to employ verbal chocolate caramels. The man has a lot of bad habits,—that is all that ails him, and it may be as hard for him to quit them as it is for you to carry out your New Year's resolutions.

You can make a real good fireman out of the poorest stick that ever held a shovel. It is just a matter of method, and I have promised to tell you about the methods that other men have found successful in dealing with their firemen. I have also promised to show how fuel waste may be stopped by the "fiat" of the Manager. It is up to me to make good in spite of the difficulties that I have just placed in my own pathway.

If you want a really good fireman in short order, go and get a husky fellow that never fired a boiler. Start him right and he will think that there is just one way to do it. He won't know how to waste your fuel. Give me a green boy from the farm and I will turn him into an expert fireman in 48 hours. There is just that little to learn about the business. But you can't always raise your fireman from a pup. You may have to take whatever material you can find or whatever is sent you by the fireman's union. This is unfortunate, because it is easier to turn a new man into a real expert than it is to break an old fireman of just one bad, wasteful habit.

Three steps must be taken to stop your fuel wastes and institute economy, viz.:

1. You must find the causes of loss and the means of

stopping the losses. I have mentioned the apparatus and the methods of procedure.

2. You must make sure that the fireman fully understands what is expected of him and you must have the means of checking the fireman. You must be able to tell each fireman at the end of the day how much fuel he has saved by carrying out your instructions, or how much fuel he has wasted by disregarding them. Commendation, when merited, is quite as important as criticism.

3. You must give the fireman some incentive to exert himself to the limit in the interest of efficiency. And the exertion called for does not mean extra labor for the fireman. It means less labor but it also means increased care and watchfulness.

Now how can you remain in your office and accomplish these three things by what I have termed, "fiat?"

You can submit the 20 questions, suggested in the first chapter, to your engineer as a starter, and ask for a specific answer to each one of them. Your "fiat" will go that far and you can tell whether the engineer is "guessing" or answering.

If he needs apparatus for testing purposes, your "fiat" will prevail with the purchasing agent. And after the apparatus has arrived you can say to the engineer,—"Here are the tools with which you are to produce fuel economy. Get busy." And you can go and have a look and see if he *is* busy. Nobody has the small-pox in your boiler room. It will be safe for you to go down there for a few minutes and watch these interesting "spotting" and stopping operations.

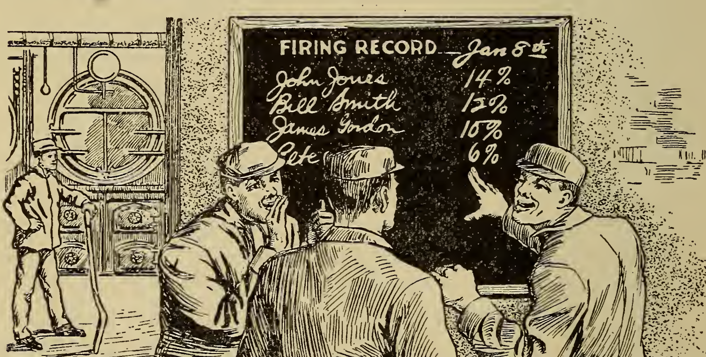
And after the checking system has been instituted your "fiat" will bring the daily chart or daily report on the firemen to your office. If it is not waiting for you in the morning you can send for the engineer and heat up the grid-iron.

If it seems advisable to capitalize economy in your boiler room and make your firemen stockholders in the enterprise, your "fiat" will establish a bonus system. If you do not want to pay a bonus, your "fiat" will place a blackboard in the boiler room on which the daily records of each man and each watch can be posted. The baseball score will be unable to compete with that blackboard for interest. When

you play each watch against every other watch, and each fireman against every other fireman, fuel economy becomes a sporting proposition. Your ingenuity may suggest other expedients to increase the interest of the game,—for example: You can put all of the white men on one watch and the niggers and the Irish on another. Being an Irishman myself I know that such division would lead to spirited competition.

Fuel economy, Mr. Manager, must be instituted and maintained by your "fiat" and it cannot be instituted and maintained in any other manner. As explained in the first chapter, when I use the term "Manager," I am referring to the person who is the court of last resort on all matters pertaining to the power department,—the man to whom the engineer must go when he wants to buy anything or to do anything out of the routine order. In some establishments, the Chief Engineer himself is this court of last resort, and in such cases he is the man to whom I am referring when I say "Manager."

The "Manager," whoever he may be, must start things on the road to betterment and he can make betterment "stay put" when it is achieved by causing whatever checking system he may adopt to be treated as a part of the daily routine. No other method will get you anywhere. What applies to the establishment of any other factory reform or innovation, applies in this case also.



They're Making Fun of "Pete."
He's the Lowest on the List.

How shall we check the "fireman" and make sure that he is really following the methods that will produce the most steam with the least fuel?

Flue gas analysis serves two purposes in the boiler room, viz.:

First: It points out the errors of furnace management. It locates the wastes of energy, assigns the causes and suggests the remedies. It assists in "building up" furnace efficiency. This building up operation is like any other one. It is a case of one brick upon another until the structure is completed.

Second: It serves as a check upon the furnace and the fireman and maintains the efficiency structure after the building has been finished.

I must not be understood to mean that combustion analysis has no limitations in the good that it can accomplish in the boiler room. No furnace can be operated under ideal conditions, for reasons that are known to every operating engineer. The load fluctuates and the moods of the coal dealer are subject to changes. These things must be taken as they come and we must make the most of them. Many engineers take the following position and it seems to me quite untenable: "With our ragged load line, our rotten coal and our poor firemen we are up against it and we can make no pretensions of economy. The methods recommended would work out very well in most plants but it would be useless to attempt them in ours."

It seems to me that the harder the conditions are in the boiler room, the more important it is that an effort be made to correct them. The sicker you are the more you need the help of medicine. Suppose it *is* impossible to place your plant upon as high a plane of efficiency as that enjoyed by your neighbor? The savings actually possible to you may be far greater than your neighbor can make, and a dollar is a dollar wherever you find it.

A few years ago I was called to a down-town plant in Chicago. It was mid-summer and there was very little use for steam. There was one large boiler in service and it was being operated at only about 20 per cent of its capacity. The boiler was served by a type of stoker that made a re-

duction of grate surface impossible. The plant needed a small boiler unit for the summer load, but it didn't have one. The flue gases were carrying only 2 per cent CO_2, which you will find on reference to the charts and tables given elsewhere indicated a preventable loss of nearly three-quarters of the fuel burned. We were able to get 4 per cent with very little trouble and without lifting the safety valves, but we could not get more than that without blowing off steam.

The engineer said, "What's the use? I am as much ashamed of 4 per cent as 2 per cent." The use was just this: That 2 per cent increase in CO_2 meant a saving of about 43 per cent of the fuel, and while at 4 per cent there was still a waste of 31 per cent that he could not avoid, the 43 per cent that he could stop was mighty well worth going after.

If you are in the bad lands of engineering and can get where the lands are not quite so bad, it is your duty to emigrate. You would be foolish to stay where you are just because you can't reach the land of Beulah. The best anybody can do is to do the best he can do and it is a foolish man who will not try at all because he knows the ideal is unattainable.

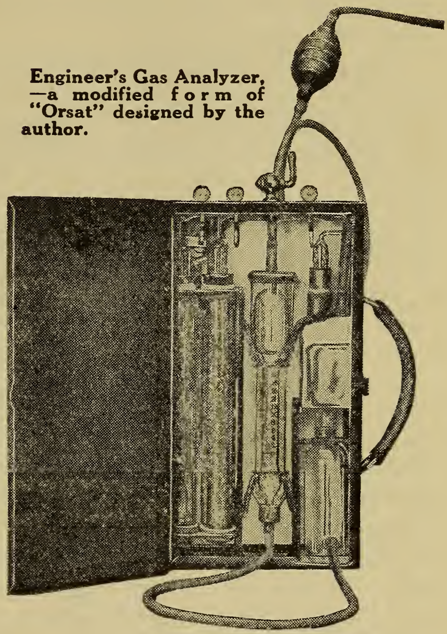
I regard the simple hand manipulated Gas Analyzer as indispensable to the steam power plant. You can "build up" with it and when this has been done you can check the fireman with it provided you have some satisfactory means of collecting an average gas sample.

The Instrument shown elsewhere was designed by the author expressly for the class of work in the boiler room that has been described in these pages. It is a modified form of the well known laboratory Orsat. The laboratory features have been eliminated and other features have been added which adapt the apparatus for the engineer's uses. A determination of CO_2 may be made in 45 seconds with this Instrument.

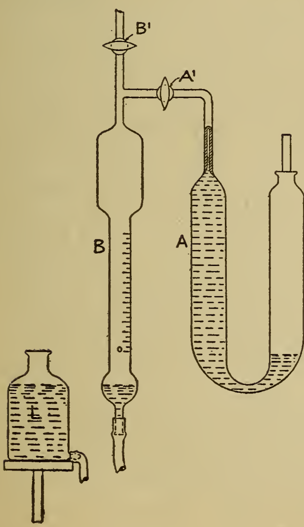
The drawing shows the principle of the Orsat Analyzer as designed by the chemist, Orsat, about 50 years ago. An explanation is appended to it. In speaking of the Orsat it is only fair to mention the Hempel and Elliot Gas Analyzers,

Illustration Showing the "Orsat" Principle of Gas Analysis.

The gas to be analyzed is taken into the "burette" "B" the cock "B1," being opened for the purpose. The "Leveling Bottle" "L" is filled with water. "L" is then raised with the hand and water flows from it through the connecting rubber tube into "B," "seeking its level." "B1" is closed when the water reaches the zero mark on the scale etched on "B." The water levels in "B" and "L" should then be in the same horizontal plane, thus giving a measurement at atmospheric pressure of the exact gas sample called for by the "burette."



Engineer's Gas Analyzer, —a modified form of "Orsat" designed by the author.



"A" is charged with a gas absorbing liquid. The cock "A1" is opened and "L" raised, the water driving the gas from "B" into "A," displacing the liquid in the latter. The CO_2 contained in the gas is absorbed by the liquid and this causes a contraction in the gas sample. The gas remaining is then pulled back into "B" by lowering the Leveling Bottle. The chemical (Caustic Potash solution) must be drawn up into the capillary tube at the top of "A" before the cock "A1" is closed.

The bottle "L" is then held in such position that the surface of the water is in the same horizontal plane as that of the water in "B." This places the gas under atmospheric pressure and the reading is taken.

Additional absorber pipettes, similar to "A," are connected by a manifold with "B" and charged with the proper solutions if Oxygen and CO are to be determined.

which together with several others are obtainable of any laboratory supply house.

All of the present methods of Gas Analysis by absorption have been in use for a half a century in the laboratory. These methods were devised long before any one dreamed of using a Gas Analyzer in the boiler room and hence the laboratory features. The author worked with all of these Instruments prior to designing his own apparatus, and was driven by the exigencies of the situation to devise something suited to the requirements of the boiler room.

About eight years ago the author began experimenting with devices to collect average gas samples. When the fireman has been shown how to produce 14 or 15 per cent CO_2 it is essential, if you would maintain any sort of check upon him, to know at the end of the day how much CO_2 he has in fact produced on the average during the day. To this end a device to draw a continuous stream of gas into a receptacle at a uniform rate throughout whatever period the fireman may be on watch, is necessary. It is an easy matter to get gas into a can or bottle and get it out again for analysis. All you have to do is to connect the bottle at the top by a tube with the flue through which the gas is passing, fill the bottle with water and allow the water to run out slowly from the bottle. As the water head falls gas is drawn into the bottle. This is the principle upon which all gas collecting devices have been based and the trouble with it is that it requires considerable modification before it can be used. To collect an *average* gas sample is one of the hard things that look easy and unless the sample *is* an average one it may be very misleading.

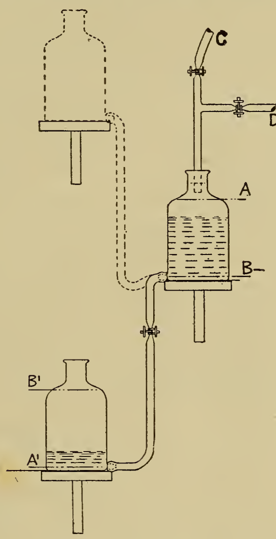
The rate at which water will flow from a tank or bottle depends upon two things, viz.,—the opening through which the water is allowed to escape and the head of water above the opening. As the head falls the rate of outflow decreases and it is plain to be seen that the inflow of gas depends upon the outflow of water.

The author's first experiments with Gas Collectors were conducted at the plant of one of the brewing companies in Chicago. He produced a really ridiculous contrivance and abandoned it at the end of the first day. It is shown in

How the Author Made a Fool of Himself

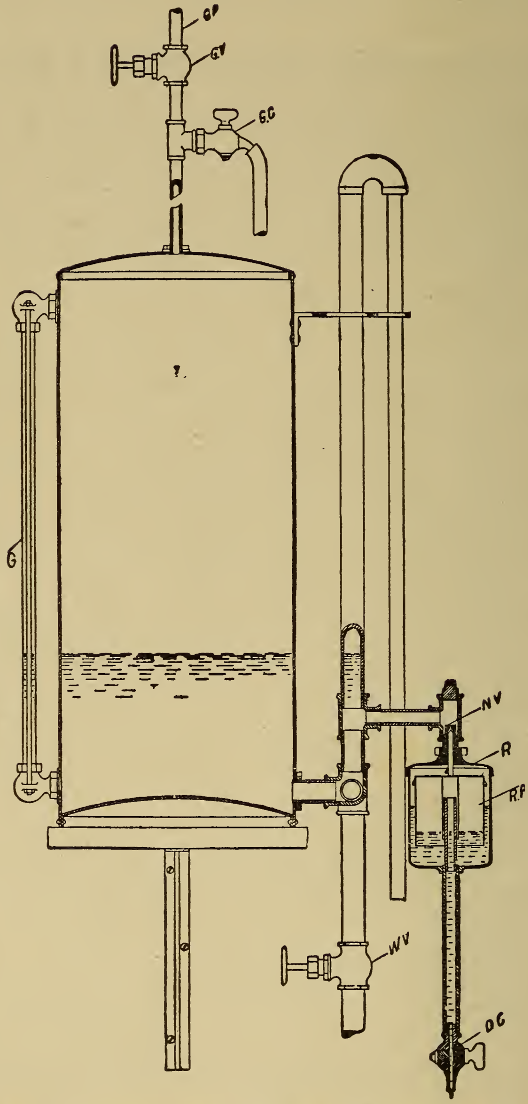
The illustration shows the Author's first Gas Collecting device, referred to on another page. Water was allowed to drain from the upper bottle into the lower one, the rate of flow being fixed by a pinch clamp on the connecting rubber tube. As the water fell gas was drawn in through the tube "C"

It was intended that the lower bottle should be set upon the upper shelf, as shown by the dotted lines in the illustration,



when ready to analyze the gas sample. The clamp on the tube "C" could then be closed and the one on the connecting rubber tube removed. Water would then flow by gravity back into the first bottle and drive the gas out through the tube "D" to the Gas Analyzer.

The trouble with this arrangement was that on the start of the gas collecting operation the water stood at "A" in the upper bottle and at "A1" in the lower bottle, while at the conclusion of the operation the levels were at "B" and "B1" respectively. These differences in head defeated the object of the device, that of collecting an AVERAGE gas sample.



Gas Collector, with Water Flow Regulator

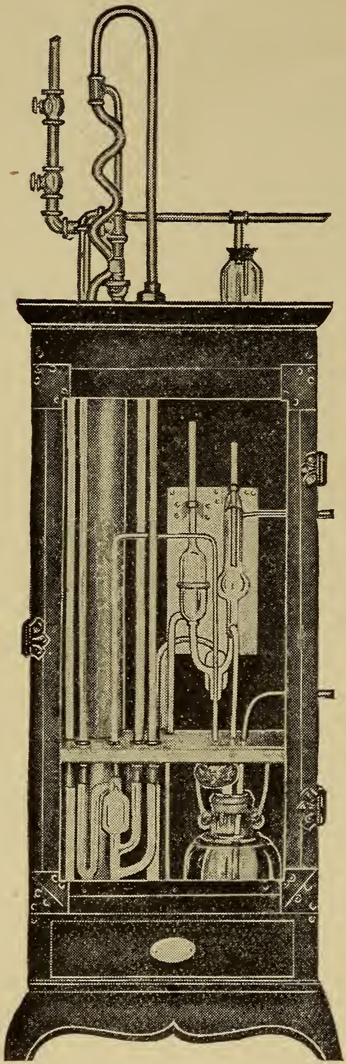
(Designed by the Author)

the sketch preceding. The thing took gas many times faster on the start than on the finish, so that it was utterly impossible to say at the end of the watch what the real average for the watch had been. The only case in which such a device could be used would be where the percentage of CO_2 is uniform throughout the entire watch and in such case it would be unnecessary to employ a Gas Collector at all as a single snap shot sample taken at any time during the day would provide the necessary information. Unhappily the CO_2 percentage is constantly fluctuating and if we would know the real efficiency of the fireman we must know the real average produced by him. When he is cleaning fires a large excess of air will be taken and this will of course affect the sample collected. It will be seen that it would make a lot of difference whether the Collector was running fast or slow during the cleaning operation. In some plants there are many periods during the day when the boilers are hit with unusual loads and other periods when the loads are extremely light. Extraordinary care must be exercised by the fireman at these times or he will waste a great deal of fuel. It is very obvious that with such a gas collecting scheme as the author first devised the engineer would be quite unable to say what the fireman's efficiency had been.

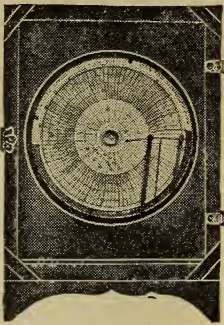
Some men have to be hit with a brick before they can see anything and a good sized one hit the author when he stood in front of his first gas collector and watched it operate. The thing started with quite a respectable outflow of water. By the end of the second hour the stream had slowed down to a drizzle pizzle. From then on the rate of discharge suffered a constant decrease.

Any school-boy student of physics would have been able to predict this result because every school-boy knows that the pressure at the outflow opening depends upon the head of water above the opening. In this case the author had a falling head of water in the upper bottle and a rising head of water in the lower one.

Since that time the author has designed a number of gas collecting devices, all of them equipped with flow-regulators. One of these is shown in the illustration on the preceding page.



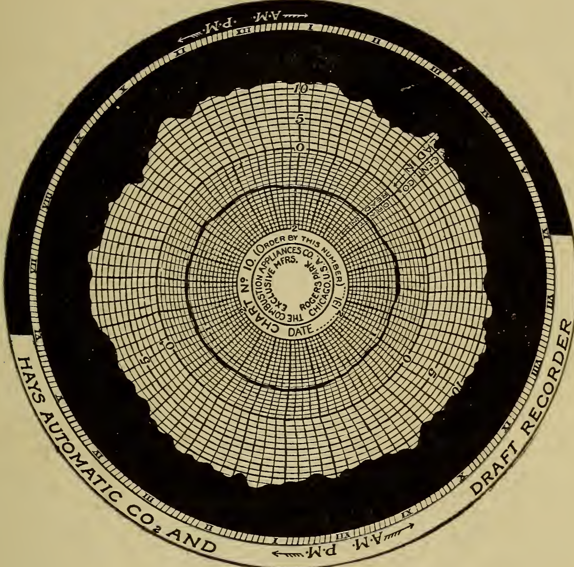
The Automatic Analyzer



The Recording Gage

Automatic CO_2 and Draft Recorder

(Designed by the Author)



What a CO_2 Recorder Chart looks like

The automatic CO_2 Recorder may be substituted for the Gas Collector if desired, but it is, of course, more expensive. It produces a graphic chart which shows the fluctuations in the CO_2 content of the gases throughout the day. The author has designed a Recorder which will be found illustrated on another page.

The Collector has the following advantages over the Recorder:

1. The cost is much lower and it is possible to equip an entire boiler plant with Collectors at the expense of equipping one boiler with a Recorder. You cannot expect 100 per cent results unless you have a 100 per cent equipment and anything less than an equipment for each boiler is less than 100 per cent.

Suppose, for example, that you have a checking device, either a Collector or a Recorder on but one boiler. The firemen will know which boiler is being checked and that boiler will get most of the attention. The result may be

that the over-all efficiency of the plant is less than before the equipment was put in use. The firemen may so neglect the furnaces that are not being checked in order to make a good showing on the one that is under supervision, that the result may be an actual fuel loss instead of a fuel saving. In such a case the apparatus would work to fool the Manager and Engineer of the plant rather than to check the fireman.

2. When you have a Collector or Recorder on each boiler the firemen cannot play favorites and if one boiler furnace does not perform as well as another and persists in its failure you may presume with considerable assurance that an air leak has developed somewhere or that something else beyond the jurisdiction of the fireman has intervened. You will look into that boiler and find the trouble.

There should be a draft gage connected with each boiler furnace so that the fireman will be able to equalize the drafts. The gage will further assist the fireman by indicating when the fuel bed has burned down too thin or has developed air leaks. The gage will show a marked drop in the draft under such circumstances. The fireman will learn in a short time to watch the draft gage as he watches the steam and water gages.

3. It is quite essential at times to check the furnace gases for the average CO as well as CO_2. This is possible where the Gas Collectors are employed. It is impossible where CO_2 Recorders are used.

4. The average CO_2 cannot be determined closely from a CO_2 Recorder chart. It can be determined very closely by analysis of the gas trapped in the Collector. And it is quite essential that you should know the average, especially if the percentage is low. By referring to the tables previously given, you will note that in the lower ranges of CO_2 every fraction of a per cent counts for something. If your firemen are reducing the preventable loss, even at as slow a pace as one per cent of coal a day you have reason for rejoicing. They will get there in 25 days if they keep it up, provided your waste is 25 per cent. You want to know whether you are progressing, standing still or retrograding. This you can learn by means of the hand Analyzer

and Gas Collector. When you compare two CO_2 Recorder charts you will have some trouble to determine which is really the best if the charts are anywhere near alike as to averages.

The above are the advantages of the Gas Collector over the Recorder.

The advantage of the Recorder lies in the fact that it produces a graphic chart, which shows not only what happened, but when it happened. The chart may also be made to show the draft and the temperature of the escaping flue gases by combining with the CO_2 recording gage the necessary draft and temperature recording apparatus. Such a combined chart would accordingly show any relation that might exist between the CO_2, the draft and the temperature of the escaping gases.

CO_2 Recorders have been upon the American market for about eight years and it is putting it mildly to say that they have given themselves a black eye in steam power plants. Both eyes have in fact been decorated. The circumstancs are unfortunate and they are due to the following causes:

1st. The inherent defects in the earlier Recorders, which the author is pleased to say have now been largely remedied in most of the later Recorders and entirely remedied in some of them.

2nd. Failure on the part of Recorder manufacturers to explain, and failure on the part of Recorder purchasers to understand, what the real functions and limitations of the CO_2 Recorder are.

As a result of these two things CO_2 Recorders have a bad reputation and it takes time to live that sort of a reputation down. You will find hundreds of Recorders standing unused today in the dark corners of steam power plants and if you wish to make some power men see red all that you have to do is to mention CO_2 Recorders.

The CO_2 Recorder has been greatly overestimated by the manufacturers and it is at present greatly misunderstood by the public. It is high time for somebody to stand up and spit out the facts about the apparatus. I shall endeavor to write the truth in as unprejudiced a manner as possible.

If you will talk with many of the engineers who have used CO_2 Recorders you will get this sort of an expression from them:

"The Recorder would probably be all right and help us a great deal if it would only 'run.' The one we have never ran long enough to give us a line on anything."

Any apparatus that requires a couple of college professors in constant attendance to keep it in operation has no place in a steam power plant. We may even go so far as to say that any recording apparatus that requires more than the irreducible minimum of attention has no business in an engine room and less than no business in a boiler room.

The requisites of a practical CO_2 Recorder are as follows:

1. It must "stay put" and keep on running indefinitely after it has been started.

2. It must require no attention other than that necessary to change the chart, renew the chemicals and change the filtering material in the gas line.

3. It must be automatic in all particulars, including the adjustments that are necessary to compensate for changes of temperature, changes of volume and of specific gravity in the absorbent solution, changes of draft in the boiler, etc. In other words the apparatus must look after itself and take care of all of the variables with which a CO_2 Recorder is forced to contend.

4. There must be the minimum of moving reciprocating parts. The less there are of them the longer the apparatus will "stay put," because it is in the nature of mechanical contrivances to get out of order, especially when they are of the delicate nature demanded in an apparatus of the kind considered.

In some of the earlier Recorders there were as many as 50 points of adjustment and it required an expert adjuster to keep the apparatus in proper operation. Some of the modern Recorders have no points of manual adjustment whatever and no mechanical parts whatever. It is accordingly possible today to secure an apparatus that will meet the requirements as above set forth.

In soliciting proposals from the manufacturers of CO_2

Recorders the author suggests that guaranties be asked upon the following points:

1. The length of time that the apparatus will be guaranteed to operate properly without attention other than that required to change the chart, renew the chemical for absorbing the CO_2 and change the filtering material used to clean the gas.
2. The annual cost of upkeep, including the cost for charts and chemicals.

A statement should also be asked as to the method of controlling the variables of temperature, etc., referred to in a preceding paragraph, the number of the points of adjustment about the apparatus and the extent to which movable mechanical parts are employed.

With the information on the points suggested in hand you will know which apparatus to purchase and where to get it.

The earlier Recorders failed, first because of inherent defects in the Recorders themselves and second because the apparatus, when it did work, could not live up to the claims made for it by the manufacturers,

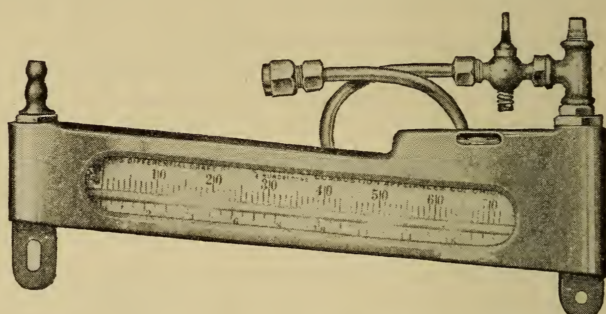
Now, what are the functions of a CO_2 Recorder?

The apparatus is a watchman and a good one but no more. It will help you to keep the wastes stopped after you have first "spotted" them and stopped them. It will help you to maintain efficiency after you have attained it. It is not the proper apparatus for "diagnosing" combustion troubles or "building up furnace" efficiency. I do not say that you cannot diagnose or build up with it. I say that it is not the *proper* apparatus for that purpose and I make that statement because with a hand analyzer I can do more "diagnosing" and "building up" in an hour than I can do with a CO_2 Recorder in a month, and I can diagnose some things with the hand Instrument that I could not attempt at all with a Recorder. There is no sense in waiting a month for the information that you can obtain in an hour and there is no sense in paying a high price for an unsuitable "diagnosing" apparatus when you can get one at a low price that is exactly adapted to the work required.

The CO_2 Recorder will tell you in what way the fireman

has carried out your instructions, whether he has observed the methods that your investigations with the hand Instrument have proved to be necessary. It will spur each one of your firemen to his best efforts because it is human nature to be more careful when there is a watchman looking on. It is human nature to hustle when the race is on with another man.

There is a CO_2 Recorder in an Eastern power plant and considerable competition among the firemen. One of the men succeeded in making a particularly good record and he led his fellows to the Recorder gage, exhibited the chart



Differential Draft Gage

(Designed by the Author)

and invited them to "Go to it and beat *that.*" While none of them succeeded in beating it, some of them did succeed in measuring up to it.

With the hand Instrument you can make sure that your boiler setting is in proper condition,—you can test here, there and wherever you wish with it. You can, as I have explained, look at the furnace when you look at the Instrument and you can refer the result of each analysis to the observed furnace conditions that produced the result. You cannot do this with a Recorder. Don't let any salesman persuade you that you can.

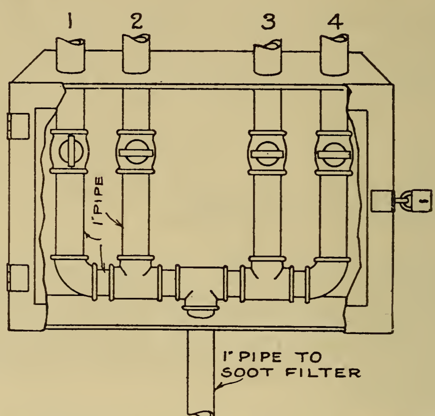
It takes time to get the gas from the boiler to the Recorder. It must flow through a considerable length of pipe and through soot filters. There is necessarily some

"lag" on this account. The "lag" may be anywhere from two minutes to fifteen minutes. The less of it the better. On account of this the fireman cannot guide his operations by any CO_2 Recorder chart or by any "CO_2 Indicator" accessory to the Recorder. To be sure, the Chart and the Indicator of the Recorder will tell the fireman that there is a hole in the fire, but it will report the information anywhere from 2 to 15 minutes after the hole began business. A differential draft gage will report the hole the instant that the hole appears and the fireman can get instant action. You need gages for the purpose of draft equalization as set forth in a previous chapter. Have your firemen rely upon them as indicators of furnace conditions. Any manufacturer of CO_2 Recorders will be glad to supply you with a CO_2 Indicator if you are foolish enough to order such an attachment. Don't order it because it is liable to do more harm than good. It will report a hole in the fire after the fireman has fixed the hole and it will report a good fire when there are in fact holes that need stopping. This is due to the necessary time interval that intervenes between the taking of the gas from the boiler and the report on that gas by the Recorder.

I repeat that the functions of the Recorder are those of a watchman. Let it watch the fireman for you and let the fireman watch his fires. If he does that, the Recorder will make a good report upon him. Watching the chart of the Recorder will assist the fireman to some extent, as it will show him the result of what he did some minutes ago. In other words it will enable him to work out things if he has the intelligence to observe, interpret and draw conclusions. But I maintain that it is better to show the fireman, by means of object lessons with the hand Analyzer, what is and what is not a proper "fire," also what is and what is not the proper draft for that fire. Thereafter let the fireman watch the fires and the draft gage and set your CO_2 Recorder to watch *him*. This will keep the fireman reasonably busy and if he attends to business the Recorder will have a good report to make upon him.

There should be one CO_2 Recorder for each boiler, but this may mean more of an expenditure than you care to

incur. One Recorder for a battery of boilers may prove a serious mistake, unless the piping is so arranged that the firemen will have no means of knowing from which boiler the gas is being drawn. Suppose, for example, that *you* were a fireman and that you knew the Recorder to be working on the gas from Number 1 boiler. In spite of yourself you would give more attention to that boiler than



Arrangement of Piping Enabling One Recorder to Serve a Battery of Four Boilers

to any other one. You would want to produce a good chart because you would know that the Manager and Engineer would inspect that chart. But if you had no means of knowing which boiler the Recorder might be reporting upon, you would take no chances. You would give the same attention to all boilers, and doing this you would be sure to produce a good chart.

Your Recorder or your Gas Collector will work upon but one boiler at a time. If you have several boilers in operation and but one Recorder, run the individual gas pipes into a common header. Place a valve on each gas pipe near the header and box the valves in such a way that the firemen will have no means of knowing which valve is open. Then switch the Recorder from time to time and you will have a reasonably good check on the entire plant, though not so

good a one as you would have if you were provided with a full equipment of Recorders.

If you wish to establish a bonus system in your fire-room, and such a system always brings results where all else fails, an equipment of Collectors will be in some respects better adapted to your purpose than Recorders, because your bonuses must be paid on averages and the Collector deals in averages at the expense of details, whereas the Recorder deals in details at the expense of averages. You can get the approximate averages by running a planimeter over the Recorder charts, but you can get the exact average within one-fifth of a per cent CO_2 by analyzing the gas trapped in the Collector. When using the Collectors you must depend upon some one to make the analyses. If that person turns in false reports, either designedly or otherwise, your bonus system will be unfair to some of the firemen and unfair to yourself. The Recorder will turn in a correct report within the limits of its accuracy. Surely there is some one about your plant who can be relied upon to analyze the gas taken by the Collectors. If the man to whom that work is entrusted is under suspicion a trap can easily be set for him and if he is guilty he will step into it.

I was asked for advice not long ago by a plant Manager. He was uncertain whether to buy Collectors or Recorders. I stated the pros and cons of it much as I have stated them in this chapter. He said, "We are wasting so much fuel that we can afford to do this thing right. I shall buy a Recorder for each boiler." Another Manager after a similar interview decided in favor of the Collectors, because he found that he could equip each of his ten boilers with Collectors at the cost of equipping a single boiler with a Recorder.

It is very largely a matter of choice whether you adopt Collectors or Recorders, and I have tried to set forth the facts as I see them in order that you may have the data upon which to base your choice.

The reader will understand that in my discussion of the apparatus required for combustion analysis I am not depreciating any related apparatus by my failure to mention it. Water meters and steam flow meters have their uses in the

boiler room. The same may be said of recording pyrometers and other apparatus. The further such apparatus goes in the analysis of conditions and the location of causes the more reason there is for its presence.

The feed water meter and steam flow meter talk about capacity without relation to efficiency, while the CO_2 Recorder talks about efficiency without relation to capacity. There is no way that the one form of apparatus can be substituted for the other. Some men, however, are so violently partisan as to claim that such substitution can be made. It is even claimed that an arrangement of pryometers showing the temperature drop between the furnace and the uptake may be substituted for everything else that I have mentioned. All such claims as these are absurd and instead of boosting any particular apparatus, they hurt all apparatus. It is better to stick to facts, especially when the facts are so patent.

I have included a thermometer or pyrometer for measuring the temperature of the escaping gases among the desirable testing apparatus of the boiler room. It will give you more information on boiler efficiency than on furnace efficiency. For this reason I have said very little about temperatures in connection with the flue gases. When we have done all that it is possible to do to secure economical combustion it is then up to the boiler to take the heat energy handed to it. The furnace must not rob the boiler by turning cold air into the gases or by sending combustible gas up the chimney. When the furnace can show that it has discharged its functions properly, the boiler is responsible for any excess temperature that the escaping gases may show. The temperature should not be more than 100 degrees Fahrenheit above that of the steam in the boiler.

Take your flue gas temperatures at the point where the gases leave the heating surfaces of the boiler, as I have already advised. I sometimes hear engineers boasting about extremely low stack temperatures and in almost every case of this kind I have found that the temperatures were taken in the breeching or at some other improper point.

And now let me briefly recapitulate the steps that you must take to substitute economy for the waste that is ruling your boiler room.

First, you must get yourself "under conviction of your sins," as the revivalist would express it. You must really want all of the economy that is coming to you and determine to get it.

Second, you must "diagnose" your waste troubles and discover the remedies called for.

Third, you must make the firemen understand what is expected of them and they must be convinced that your contentions are right. If the fireman does not agree with you on any subject relating to the management of the fires you must convince him that you are right and he is wrong. This is easy.

In a big Eastern power plant there is a negro fireman who rejoices in the nickname of "Happy." He was persuaded that he was some fireman and it would have been impossible to argue him out of that hallucination. The Chief Engineer had tried arguments without success. He decided to give "Happy" an object lesson and as the man was looked upon as an expert by the other negro firemen the Chief considered the object lesson as of sufficient importance to warrant a couple of evaporative tests.

A ten-hour test was run with "Happy" as fireman and he was instructed to do his "darndest" as they were trying for a record. The man was allowed to fire in his own way and he was a tired man at the end of the day.

On the following morning the Chief Engineer said: "Happy, we are going to run another test today and you are going to fire again. You fired your way yesterday and today you are going to fire my way. I shall stay with you and you will fire exactly as I say. We will not stop the test until we have evaporated as much water as we did yesterday."

The test was conducted under this arrangement and it was concluded at the end of nine hours. The Chief then pointed to the large pile of coal that was left and said, "Happy, what would you think of a fireman who would steal that amount of coal from his employer?" "Why," said Happy, "Ah nevah stole no coal from this company. Ah nevah stole no coal from nobody." "I know it," said the Chief, "but you have wasted coal every day and wasting

coal is worse than stealing it, because nobody gets any use of fuel that is wasted. We evaporated as much water today as we evaporated yesterday. We have an hour to spare and as much coal to spare as you see lying on the floor." "Is you sure about the evaporation?" said "Happy." "Why Ah worked like a niggah yesterday and today Ah hardly worked at all. Ah didn't suppose the boiler was doing anything." "Happy" was convinced and ready to take instructions where before he would accept instructions from nobody. Today he is said to be one of the most expert firemen in the city of Pittsburgh.

It is not necessary to run an evaporative test to give your fireman an object lesson. You can give very convincing lessons with the "spotting" apparatus I have mentioned.

For the fourth step you must institute a checking system in your plant as already suggested and the fifth and final step is taken when the incentive for ultimate effort is given by a bonus system, or otherwise.

I have never known a bonus system to fail of the most gratifying results. I know of nothing upon which you can base a more equitable bonus system than the CO_2 averages. From the tables given you can arrange a bonus schedule to suit yourself. Make your firemen stockholders in your economy enterprise and they will work their shirts off to earn dividends. And as a gratifying by-product of your bonus system, your firemen will be anchored to your plant. You know what it means to have firemen quit when firemen are hard to get.

I have talked with the Managers of many plants where bonus systems are in force and I have yet to find one who is dissatisfied with the results. The firemen are always happy. In most cases the rule is to distribute about one tenth of the money saved among the men saving it, the distribution to be pro-rata according to each man's efficiency. The savings are figured from the CO_2 percentages. In some cases these percentages are checked by the coal and kilowatt records. When the figures fail to check it is assumed that something is wrong with the boilers proper or that something requires attention in the engine room. When the CO_2 reports are right it is known that the firemen and the furnaces are not to blame for any

slip in efficiency that may be indicated by the coal and kilowatt records.

The Manager of a plant on the Texas border, who employs Mexicans as firemen, writes as follows:

"I offer each man a bonus of five per cent of the fuel that he can save and the effect has been magical. The men come to me and in their broken English try to explain how hard they are trying to carry out my instructions.

Each man received a bonus of $3.75 the first month, $2.50 the second month, $3.30 the third and $7.80 the fourth. The plant was only running half the time the first three months and from all indications the bonus will be from seven to ten dollars per month in the future.

In four months each man had received $17.35 extra pay and the fuel account was benefitted by a saving of $312.30, which was all 'velvet' as no money had been invested by the company to accomplish the saving.

After this experience I firmly believe that this is the only way to handle firemen. It is simply a case of deciding whether the money is to be given to the fuel dealer or divided between the men and the company."

An Eastern plant adopted the bonus system and saved 30 per cent on its fuel the first year. The men were paid 10 per cent of the saving effected, leaving the company a net saving of 27 per cent with no investment whatever except the small amount required for CO_2 apparatus.

The bonus schedule in force in this plant is as follows:

Per cent CO_2	Premium per day
12	$0.75
11.5	.70
11	.65
10.5	.60
10	.55
9.5	.50
9	.45
8.5	.40
8	.35
7.5	.30
7.	.25
6.5	.20
6	.15

The Manager of another Eastern factory writes me as follows concerning his bonus system:

"In order to get the very best results and the most economical method of firing we are paying a bonus to the fireman who is on watch from 4 A. M. to 12 Noon and from 12 Noon to 8 P. M. on all days when the factory is in full operation. We pay bonus as follows:

For 10% CO_2, 10c; for 11%, 15c; for 12%, 25c; and for 13%, 40c. In addition to this we pay $2.00 extra each month to the fireman making the highest average the month.

In order to show you what we are doing I enclose herewith a copy of our record for the month of June.

RECORD OF CO_2 PERCENTAGE

Month of June, 1913.

FIREMEN.

	CO_2%	Bonus	CO_2%	Bonus	CO_2%	Bonus
	C. O. Bolin		Jno. Zigalinski		Peter Rynice	
1	...	....	....	....	....	....
2	12.	.25	....	....	11.2	.15
3	10.6	.10	....	....	11.	.15
4	10.	.10	....	....	10.2	.10
5	11.1	.15	....	....	10.4	.10
6	11.6	.15	....	....	11.	.15
7	....	....	....	....	10.6	.10
8	....	....	....	....	....	....
9	....	....	12.	.25	12.6	.25
10	....	....	11.6	.15	12.6	.25
11	....	....	12.	.25	12.8	.25
12	....	....	13.2	.40	12.8	.25
13	....	....	12.9	.25	11.9	.15
14	....	....	12.4	.25	....	....
15	....	....	....	....	....	....
16	12.3	.25	12.7	.25	....	....
17	10.8	.10	12.8	.25	....	....
18	12.2	.25	12.	.25	....	....
19	12.	.25	11.6	.15	....	....
20	12.2	.25	12.4	.25	....	....
21	12.	.25	....	....	....	....
22	....	....	....	....	....	....
23	12.2	.25	....	....	12.	.25
24	13.	.40	....	....	11.	.15
25	12.	.25	....	....	11.7	.15
26	11.6	.15	....	....	11.7	.15
27	11.6	.15	....	....	11.4	.15
28	....	....	....	....	11.8	.15
29	....	....	....	....	....	....
30	....	....	12.4	.25	12.7	.25
31	....	....	....	....	....	....
Totals	187.2	$3.30	148.	$2.95	208.8	$3.15
Averages	11.7		12.3		11.6	

Jno. Zigalinski, extra bonus for best average, $2.00.

We employ three firemen and one only is on watch at a time which is 8 hours on watch and 16 hours off. On Sundays the length of the watch is changed so that the same man

will not always be on the same watch. We are burning at this time of the year about 12 tons Bit. coal every 24 hours, the cost of same is $3.35 per ton in the bin and since we started to pay bonus the percentage of CO_2 is higher and we know that our firemen are doing the best they can to get the best result, and we also know that by the bonus system and the regular use of CO_2 apparatus we have reduced the coal consumption in our boiler room."

The daily "Records of Operation" should cover, when possible, all of the items shown on the following chart:

RECORDS OF OPERATION

Date __________

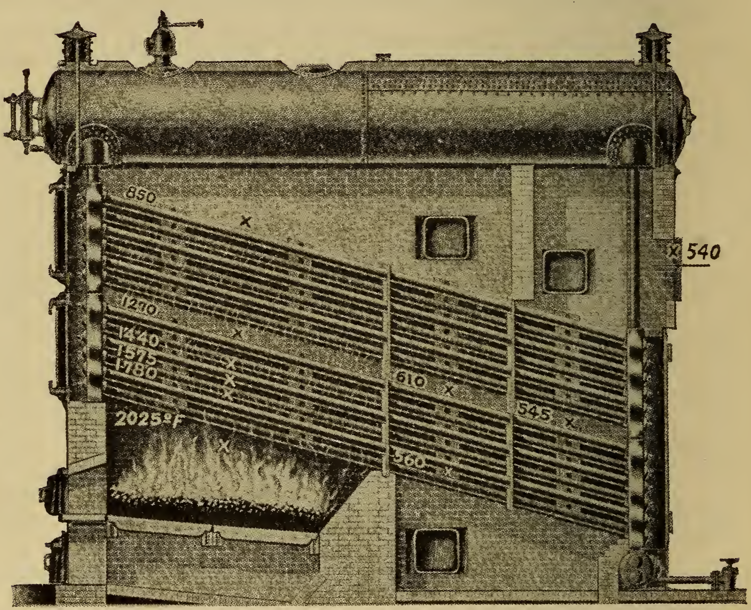
WATCH	FIREMEN	COAL	TOTAL	ASH	TOTAL	CO_2	AVGE	DRAFT	STACK TEMP	FEED WATER ENTER	FEED WATER LEAVE	WATER EVAPORATED	
1													
2													
3													
TOTALS & AVERAGES													

REMARKS __________

__________ OPERATING ENGINEER

The things that I have suggested in this book may mean a little initial expense to the management. They cannot mean much and it is just a question whether you will spend a little money for the apparatus that your engineer needs or give a great deal of money to the coal dealer. They mean a little extra trouble for the engineer, but a reasonable amount of trouble is a good thing for an engineer. It keeps him from brooding on being an engineer. I have adapted this statement from David Harum.

Showing about how the temperatures drop in the boiler passes when the heating surfaces are clean.



The only heat that counts is the heat that gets into the WATER